WESTINGHOUSE

Instruments

ARE MACHINES' VOICES

WRITERS of pseudo-science thrillers like to produce starry-eyed pieces about the machine rising up to destroy man, its inventor. Fanciful and entertaining, perhaps, but actually there is a definite reason why the machine can never get out of hand. The same ingenuity that plans the machine devises instruments to keep tab on its behavior. The machine is not a mute automaton, but, in instruments, has a voice by which it can speak to the humans it serves.

• • •

THE WAR, of course, could not continue a day without instruments. The average medium bomber has about 150 instruments to guide the pilot, radio operators, navigators, and bombardiers. Even a tank may have nearly two dozen, counting those on the radio apparatus. Also many individual soldiers, with their portable transmitting and receiving radios, have several instruments.

• • •

ALTHOUGH standard electrical instruments are being used by the tens of thousands for military aircraft, ships, tanks, etc., the needs of mechanized warfare have required many special instruments, most of which must remain undisclosed until war's end. One new instrument makes possible blind landing, by showing the pilot as he glides to a landing whether he is to the right or left of the runway as well as whether he is above or below the proper angle of descent. . . . Another new instrument shows the high-altitude flyer that oxygen is flowing to him properly. . . . It may even be possible with the aid of instruments for the individual pilot to determine during flight the actual oxygen content of his blood so that he can govern the oxygen flow to suit his needs, instead of by the "on" or "off" method at present.

• • •

DECEPTION is an important tool in warfare. Instruments have even had a vital part in this. They have helped make steel cargo boats as well as destroyers and battleships "invisible" to magnetic mines. This type of camouflage is known as degaussing. The magnetic fields inevitably set up in the steel hull and structure of a metal ship must be exactly counterbalanced by artificially produced fields. Proper control of the electric currents required would, of course, be impossible without accurate instruments, most of which are but slight modifications of already existing standard types.

• • •

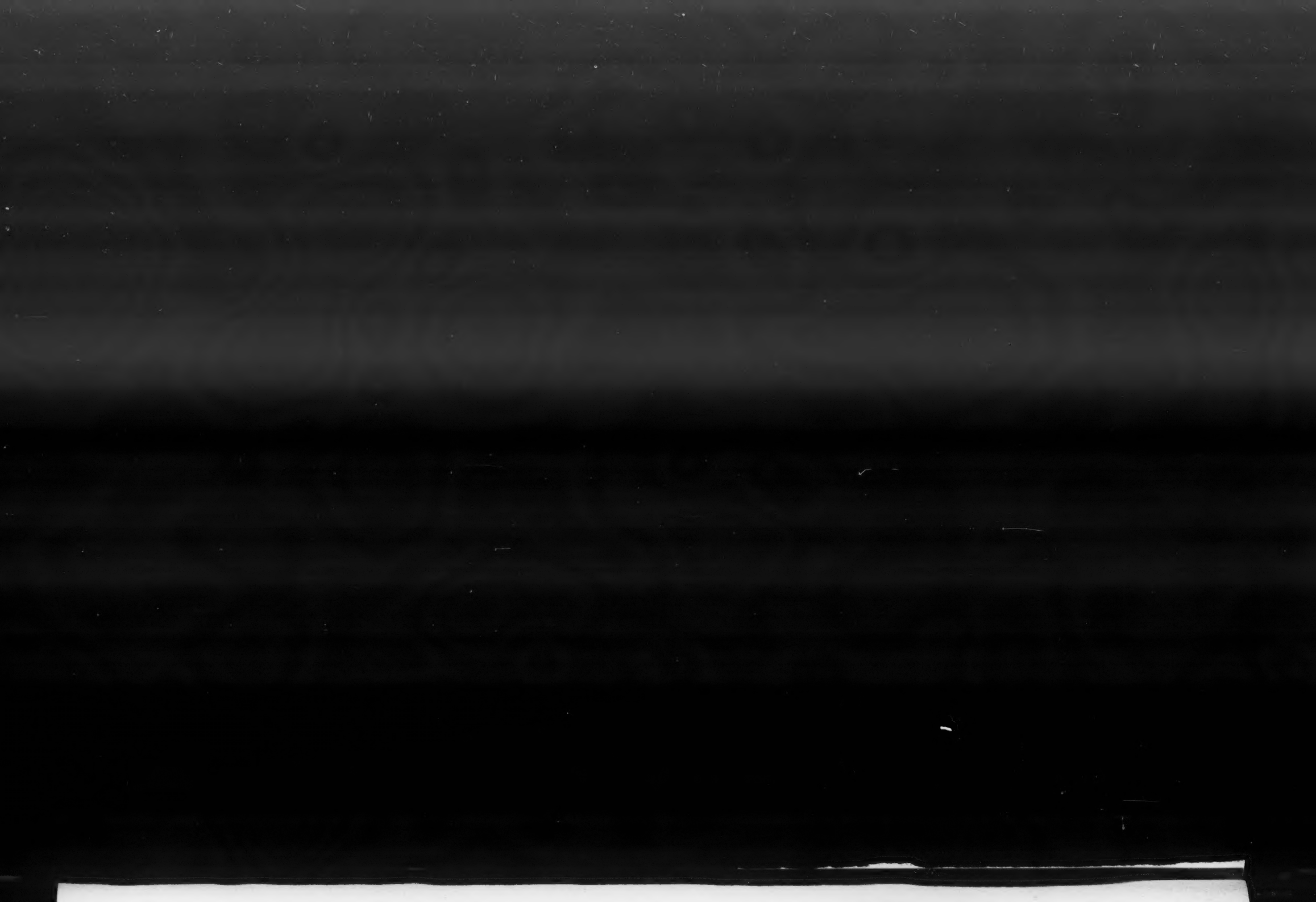
PHOSPHORESCENT, or "radium," dials on clocks, watches, and instruments is an old story to everyone. But fluorescence, the quality of being visible under invisible or black light, has suddenly become a big thing in instrumentation that guides modern warfare. The dials and pointers on the scores of instruments before a pilot must be clearly distinct, but must not be so bright as to impair his night-accustomed vision. Scales and pointers of instruments with black dials are now coated with a substance not only visible in daylight, but also that glows clearly and softly under invisible light of a special ultraviolet lamp of the fluorescent type. Furthermore, this is an unusual energy transformation. First electric energy is transformed in the lamp to the 2537 Angstrom wave length of mercury vapor. This is retransformed by the coating of phosphor on the inside of the lamp to energy primarily of 3650 Angstroms, which is just below the visible range. This energy, striking the dial coating again transformed and reradiated as energy in the green visible range, about 5200 to 5600 Angstroms.

• • •

WAR HAS imposed vastly increased duty on instruments. As against shocks, for example. On naval vessels instruments should be able to withstand shock of 1500 g. That is, each part of the instrument must be strong enough not to distort beyond the breaking point even if its weight be increased 1500 times. This is the goal to which instrument designers are now working.

• • •

A FEW years ago tiny copper-oxide rectifiers were developed to simplify measurement of high-frequency alternating currents by making it possible to use direct-current instruments. These tiny rectifiers, no larger in surface area than a printed small letter "o," are now being used in navy, army, and aircraft radio sets. The thermocouple type devices previously used, have a squared scale and an overload capacity of only about 200 per cent; the rectifier makes possible nearly linear instrument scales, and an instantaneous overload capacity of about 100000 per cent.



VOLUME TWO • NOVEMBER, 1942 • NUMBER FOUR

WESTINGHOUSE Engineer

Table of Contents

COVER: This artist's representation of resistance welding in industry, by F. G. Ackerson, conveys the idea of the increasing importance of this branch of the welding art.

Arc Welding in the Shipbuilding Industry 102
C. A. Rober and W. B. Strathdee

Resistance-Welding Machines and Their Applications 105
E. J. Del Vecchio

Electronic Control of Resistance Welding 109
T. R. Lawson

Balancing the Tin Budget 114

Electrolytic Tin-Plating Methods 117
J. Raymond Erbe

The Latest in Electric Locomotives 122

Small Damper Keeps Fan System from Oscillating 123
S. F. Henderson

Stories of Research 124

Welding by Unionmelt Process 126

The Magnetic Strain Gage, Design and Applications 129
B. F. Langer

Comparison of Lightning-Protection Devices 133
E. Beck and G. D. McCann

What's New! 136

Editor—CHARLES A. SCARLOTT · *Editorial Advisors*—R. C. BERGVALL · T. FORT · R. E. WILLIAMS

PUBLISHED QUARTERLY BY WESTINGHOUSE ELECTRIC & MFG. CO. ANNUAL SUBSCRIPTION PRICE: U.S.A., $2.00; CANADA, $2.50; OTHER $2.25. SINGLE COPIES, 50c. ADDRESS, WESTINGHOUSE ENGINEER, EAST PITTSBURGH, PA.

PRINTED IN U. S. A.

Down to the Sea in Ships, with Arc Welding

In the last war, arc welding had a position in the shipyard but little above that of the water boy. In this one, it is the dominating factor in ship fabrication. Now, nearly a fifth of the workers are in the welding and burning departments. Shipyard welding has, furthermore, followed its own course of development. Unlike general industry, in which each operator has his own exclusive welding generator, welders in shipyards are supplied with current from constant-potential generators in parallel, located in several centralized power stations.

C. A. ROBER
Welding Supervisor, Bethlehem Steel Company

W. B. STRATHDEE
Welding Supervisor, Westinghouse Electric & Mfg. Co.

IN THE early days of shipyard welding—in the era, 1915 to 1920, when current was supplied from crude generators with salt-water barrels used to control current—arc welding was used only to fasten members requiring no great strength. Among these uses were the welding of pipe, electrical hangers, rail and awning stanchions, ladder clips and rungs, flanges on low-pressure pipe, and hinges on doors and hatches. Today with welding electrodes developed to a high stage, procedures, techniques, and sequence under careful supervision and control, and wider use of special weldable alloys, welding is used on the modern vessel from stem to stern, and from keel to masthead. Shell frames and transverse frames, inner bottom floors, foundations of all kinds, deck houses, port lights and covers, high- and low-pressure piping, deck fixtures, bits and chalks, and many other shipboard structures are being welded.

A few years ago, in a yard employing 20 000 people, only a handful did welding and burning, and they usually reported to the electrical department. Today the welding and burning departments in such a yard have a welding staff of about 4000, who service all the other crafts in the yard in addition to their own work, which indicates the tremendous part welding plays today in our vast shipbuilding program. Without the aid of welding, present production of shipping could not be attained.

Shipyards Use Every Kind of Welding

The modern shipbuilding yard makes use of all types of welding apparatus, applying each to the specific use for which it is best suited. These include single-operator sets (usually d-c, but some a-c), multiple-operator sets with grid-type resistances for current control, and automatic arc-welding units with attendant controls.

The automatic welding done in the typical yard varies from five to fifteen per cent depending upon the type and class of ship. Some yards have no opportunity to apply automatics, but the larger yards usually find some work that can be done to advantage. The Unionmelt process* is the most universally used and most successful automatic process applied to this work. So far the greatest application of these automatics has been to merchant ships.

Single-operator sets in larger yards usually comprise about ten to twenty-five per cent of maximum outlets available for hand welding. They are best applied where alloy work is being done, or at isolated locations such as machine shops, pipe shops, etc., or where high currents and heavy-duty cycles are encountered. The ease by which polarity can be reversed to accommodate different types of electrodes is an advantage of the single-operator set.

The Multiple-Operator System Predominates

The remainder of the arc-welding system in these larger yards, which is seventy-five to ninety per cent of the total, consists of multiple-operator sets, sometimes called constant-potential sets. The modern shipyard ways present an extremely concentrated welding-current load. The shipyard welding problem is to get the necessary quantity of welding apparatus into the least space with a minimum movement of apparatus, with the lowest possible horsepower and connected load, and lowest cost (both first and operating). The scene of the welding operation is within the ship itself, and hence is not fixed as in the usual factory, but is changing in shape and position daily. Moving hundreds of motor-generator sets about such a changing stage is in itself a serious physical problem. But, aside from these general considerations there are several very definite reasons for the use of the multiple-operator scheme in the shipyard.

A recent survey of one yard showed 92 tackers and welders to be operating from two 1500-ampere sets in parallel. In another case, five 1500-ampere sets in parallel were supplying 164 production welders and 40 tackers. In a third yard the average per 1500-ampere set was 25 welders, working on plate thicknesses varying from twenty to forty gage. Twenty men per constant-potential set is a conservative average figure.

The total connected load is considerably less for a given number of operators, with a consequent reduction in primary wiring costs. For example, a 1500-ampere set usually supplies twenty 300-ampere circuits. This is based upon the fact that a ship welder is drawing current approximately a third to two-fifths of the time, and the actual average current including production welding and tacking is less than 150 amperes. One 1500-ampere set provides a connected load of 160 hp whereas with twenty 300-ampere sets it would be 400 hp, saving 240 hp in connected load.

The multiple-operator system has a high power factor. A station of five 1500-ampere sets, induction-motor driven, has a power factor of about 85 per cent. The power factor of twenty-five single-operator sets is about 50 per cent. This means the added expense of capacitors for power-factor correction. If the constant-potential sets are driven by synchronous motors, a leading power factor can be had by providing an excess of direct-current excitation. In this manner they can supply some power-factor correction for the other equipment of the yard.

The motors of multiple-operator sets are usually wound for 2300 volts. This is an advantage from the standpoint of power distribution because this voltage is commonly used for distribution about shipyards.

The maintenance cost of multiple-operator apparatus is considerably less—not more than half—than that of single-operator sets. Where hundreds of operators are at work this is a big factor.

The first cost is less per circuit, or for a complete setup with the multiple-operation sets, than with single-operation units. Ordinarily the choice of system to use comes down to the cost per circuit of actual equipment because installation costs are considered about equal. Actually, installation costs are much less with constant-potential sets, and feeder equipment, such as substations, cables, etc., does not have to be as large.

The constant-potential set has a better space factor than single-operation sets. Also, with individual units the voltage at the machine must be high (220, 440, or 550), which means more people are exposed to danger in a greater number of locations in a limited space on board ship.

*Described in article beginning on page 126, this issue.

Representative installations of constant-potential generators in parallel banks for producing power for multi-operator shipyard welding.

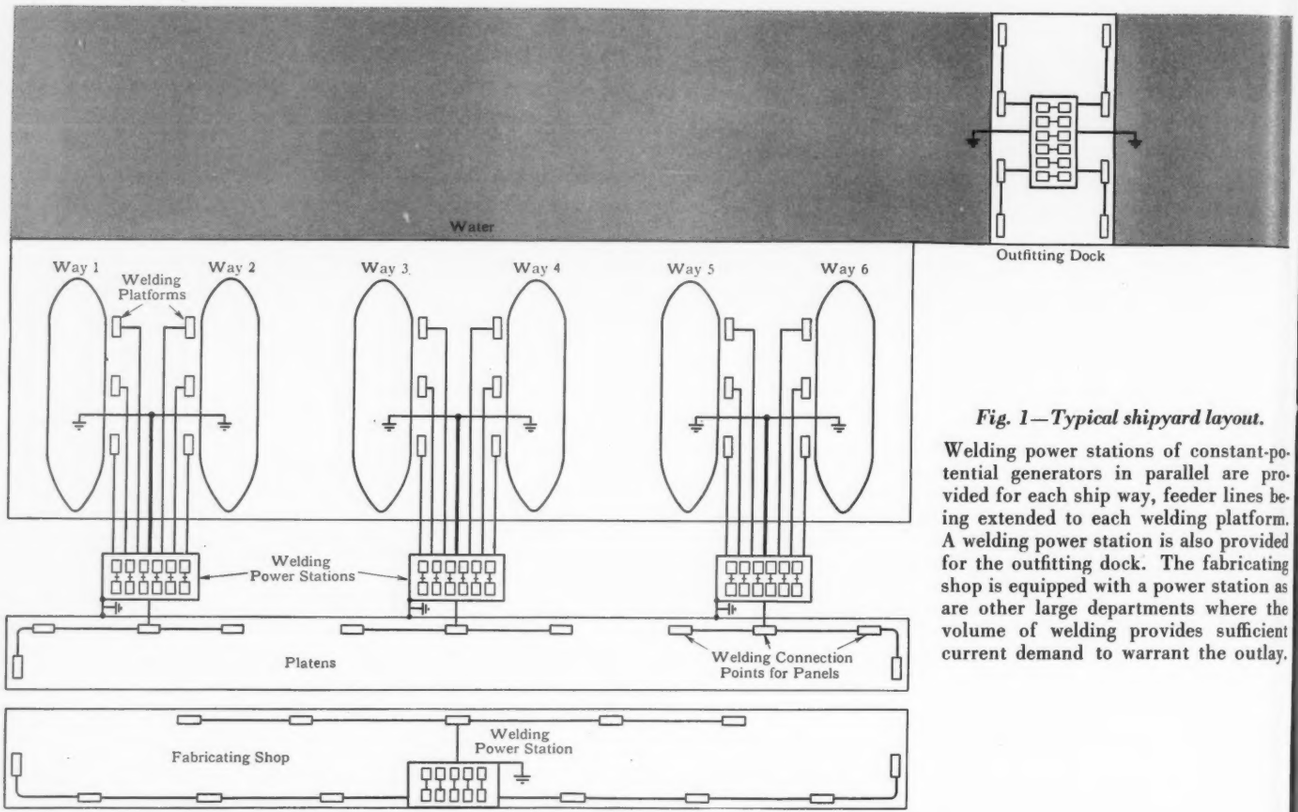


Fig. 1—Typical shipyard layout.

Welding power stations of constant-potential generators in parallel are provided for each ship way, feeder lines being extended to each welding platform. A welding power station is also provided for the outfitting dock. The fabricating shop is equipped with a power station as are other large departments where the volume of welding provides sufficient current demand to warrant the outlay.

The one disadvantage to this type of system is the question of polarity reversal. While the largest percentage of electrodes is usually reverse type, there are places where alloy work is done, or straight polarity electrodes can be used to advantage. These spots are usually covered by use of single-operator sets. However, if considerable quantities of straight polarity electrodes were to be used in certain locations, the complete constant-potential system feeding that section could, of course, be made straight and isolated from the sets feeding to the reverse polarity circuits.

Welding-Power Distribution System Resembles that of a Public Utility

A typical shipyard layout and the welding-power supply is given in Fig. 1. In each welding power station can be installed six 1500-ampere sets to be operated in parallel with provisions for one or two future additional units. These stations can also serve as a location for frequency-changer units if these are required for supplying high-frequency current to tools.

From the station can be run twelve 1 000 000-cm cables to six welding platforms between ways 1 and 2, as shown. The ground connection of ten 1 000 000-cm cables can be run down to a point about half way down the way. From this point five 1 000 000-cm cables can be run to distributed ground points on the ship.

At each platform a connector plug board serves a double type welding-operator's panel. Usually there are 250- to 500-ampere panels; each operator's panel consisting of two circuits made up of banks of switches controlling grid-type resistors by which are obtained current adjustment over the current range of panel in five-ampere steps. Welding cables are dropped from platform to ship with electrode holders attached. For a 10 000-ton cargo ship each platform would probably be arranged for about 18 double panels or a possible total of 108 men per ship per shift. Welding power can also be fed the platens behind the ways from this same station by running cables of proper sizes to these points.

Each of the welding power stations is set up the same way. By making cross connections between stations with switch tie-ins, overloads on one station can be carried by one less heavily loaded.

The fabricating shop can be supplied from the same power station or from three or four 1500-ampere sets located at a convenient central point. The ground connection can be made to the platen adjacent to the sets and the entire floor plate grounded. The line side of the generators can feed two 1 000 000-cm cables for each set. These cables can be carried the length of the shop where welding is done and across the shop at convenient points to plugboards and locations where operators' panels can be tied in.

For the outfitting dock of average length, say 1200 feet, a welding power station might be placed about midway on the dock, and equipped with four 1500-ampere sets with provision for six, if needed. From this point ground connectors can be about 150 feet in each direction, and to both sides of the dock (merely enough to pick up the ship). Also, three 1 000 000-cm cables can be extended in either direction for a distance of 500 feet with outlet plugboard connectors at three points over this distance to connect the operators' panels.

The welding of a merchant marine fleet is being literally accomplished in the heat of war. Modern equipment, efficient management, skillful labor, are compiling records inconceivable a few years ago. The efficacy of this type of layout is proving itself day by day.

Resistance-Welding Machines and Their Application

Loss in electrical energy because of ohmic resistance is a tax levied by nature on the use of electricity. Some industries, however, have made capital out of it; are, in fact, based on it, as is the incandescent lamp business. Another relative newcomer, forced to enormous stature by war needs, is resistance welding. In its many forms —spot, seam, projection, butt, flash, etc.,—each with its own merits for certain work, it is indispensable in the manufacture of planes, guns, shells, and many more of the multitudinous implements of war.

E. J. DEL VECCHIO
Chairman, Publicity Committee
Resistance Welder
Manufacturers Assn.

RESISTANCE welding is not as spectacular as its cousin, arc welding. Neither is it as well known by engineers, generally, partly because its widespread use is much more recent, and because it has taken a greater diversity of forms. The relationships and purposes of spot, seam, projection, flash, and other types of resistance welding are still not altogether clear to some electrical engineers.

Resistance welding differs fundamentally from arc, gas, or thermit welding processes in two ways: 1—The welding heat is generated within the pieces to be welded by the resistance to the flow of electric current within the work itself instead of by the application of heat from an outside source, as in the case of fusion welds. 2—A resistance weld is accomplished by the synchronized application of mechanical pressure and electric current, this resulting in a forged weld with properties superior to fusion welds both mechanically and metallurgically.

Resistance welding is basically a high-production process, and generally is not economically adapted to work where the same procedure cannot be repeated over and over. In this respect, it can be likened to stamping operations. A single blank may be more economically produced by hand methods, but if hundreds or thousands are required, a punch press and die equipment quickly repay the investment.

Several types of resistance welders are in use, each having more or less specific applications, but none can be exactly defined because their respective fields overlap. Resistance-welding applications can be divided into two broad classifications depending on whether the entire contacting surface or only a portion of it is to be welded. Thus, if two sheets are laid flat against one another, a spot weld can be made at one particular point or small area on the sheets. This includes spot welds, projection welds, and seam welds. As an example of the second type of resistance weld, consider two rods welded end to end. Here the weld occurs in all of the abutting area. This class includes butt welding of which there are two types, upset and flash.

Spot Welding

Spot welding is the simplest and best-known resistance-welding process. Spot-welding machines are* of two general types, each of which has two electrodes with their necessary electrical and mechanical appurtenances. The rocker-arm type, in which one electrode arm is hinged at the support, is the least expensive, and is generally used in the smaller capacities, up to 50-kva rating, and for steel thicknesses up to ⅛ inch. It can be operated by air, motor, or, as shown in Fig. 1, by foot. The air-operated machine differs from the one operated by foot only in that an air cylinder together with its control replaces the foot-lever mechanism. On motor-operated types a motor-driven speed reducer is placed on top of the frame. Through a cam it operates the upper rocker-arm lever.

Spot welders of larger capacities are used in the press type, as shown in Fig. 2, which is heavier and more sturdy than the rocker-arm type. The upper or movable head (platen or arm) moves in a straight line instead of an arc. This type of welder is used in various standard sizes from 30 to 400 kva, and even larger special ones are in use. They are air, motor, or hydraulically operated. Basically, a press-type welder is a projection welder. That is, it is provided with platens on which are mounted projection-welding dies. Projections are used when it is desired to make several spots simultaneously, or

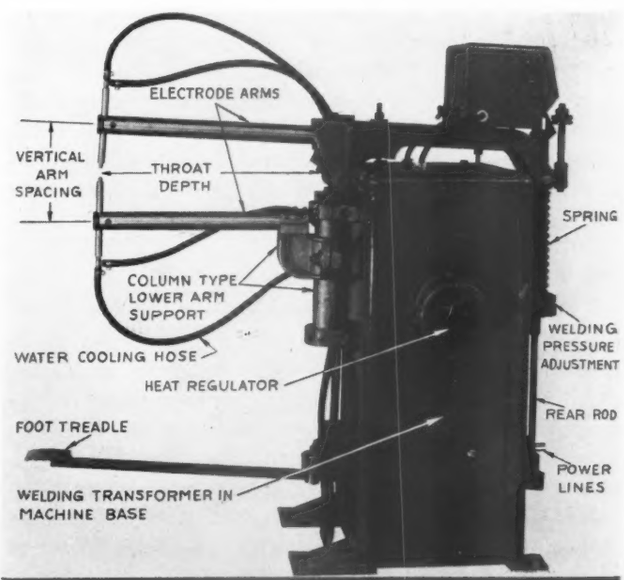


Fig. 1—Typical spot-weld machine for use with welds using up to 50 kva. Materials up to ⅛ inch are readily welded with this type, which also comes provided for air or motor operation.

*For a more complete description of resistance-welding machines see Chapters 2 and 3, "Resistance Welding Manual," of the Resistance Welders Manufacturers Association.

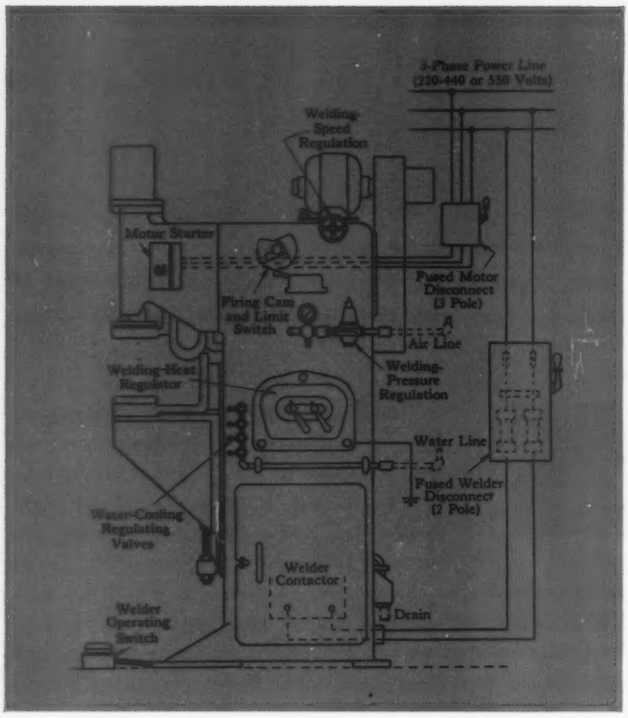


Fig. 2—Press-type welder for use with materials more than ⅛ inch thick. Ranging from 30 to 400 kva, this type is operated by air, motor, or hydraulic means. A combination air-hydraulic operation is often used. While the press type is basically a projection welder, many have provision for spot-welding use also.

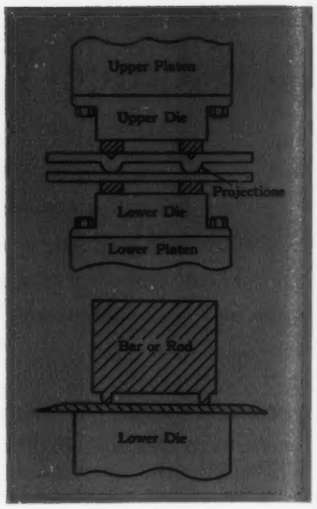


Fig. 3—Projection welding dies for use on press-type welders. These are used where it is desired to make several spot welds simultaneously. Special kinds of spot welds involving greater pressure or other factors governed by the nature of the work are also made with similar projections.

where the nature of the work does not permit plain spot welding. It is obvious from the examples shown in Fig. 3 that press-type action is necessary. Projection welders are used with rocker arms and electrode holders permitting heavy-duty spot-welding equipment only for applications as heavy armor or boiler plate, stampings, and forgings where for various reasons, projections are unsuited.

Pulsation welding, a development of the last three or four years, is generally used on all thicknesses over ⅛ inch. This consists of a series of current applications in rapid succession without the removal of electrode pressure between pulses. It is applicable for both spot and projection welding and the advantage lies in less distortion, electrode wear, and generally better welds. Without pulsation welding, spot welds in plates over about 3/16 inch in thickness are commercially impractical. The only change in the equipment required for pulsation welding is in the timing apparatus, although motor-operated machines are less suited to this kind of work than are those powered by air or hydraulic mechanisms.

Multiple Spot Welders

Multiple spot welders are furnished for high-production applications where several spot welds are to be made simultaneously. For simultaneous welds (multiple or parallel spots) pressure on each upper electrode must be applied individually, either by use of separate welding guns, or separate secondary circuit from the welding transformer. These provisions are necessary to provide the proper pressure and current balance for each spot. Simultaneous multiple welds are limited to about six or eight spots because of the difficulties of providing individual secondary circuits.

Another type of multiple spot welder is the Hydromatic welder. It consists of the machine proper, in which the work is positioned, and several welding guns hydraulically operated from a distributor mechanism that applies pressure to the electrodes in the proper sequence. Each gun is electrically connected to a common secondary bus-bar. In operation, the hydraulic distributor is started to bring the first electrode down on the work, and at the same time energizes the welding transformer to make a weld. Immediately the first weld is completed that gun lifts, and the next is operated, thus forming a rapid sequence of welds. Welding rates as high as 300 spots per minute are obtained.

The Ultraspeed welder also makes a series of rapidly recurring spot welds, but in this machine all electrodes are in contact with the work during the entire series of welds. For this reason it is necessary to connect the current feeder for each gun to the welding transformer through a commutator or distributor, so that only one is energized at a time.

In both the Hydromatic and Ultraspeed the welding transformer must be energized and timed for each weld. Also, in either of these, it is preferable to limit the guns operating from a single distributing unit to thirty or forty. Where more spots are desirable for production reasons it is necessary to provide multiple units, each with its own transformer and controls.

On these welders the only limitation to the number or location of guns is a physical one. Guns cannot be located closer together than on about 1½-inch centers. They can be placed in two or more planes, arranged in a circle or a sphere. This is an ideal application for automobile sub-assemblies as frames, doors, floors, etc., and especially when the parts are too bulky to handle on a stationary machine, and the production warrants the investment in such special equipment.

Portable Spot Welders

Where the work is too bulky to move to stationary machines, and where production cannot justify such equipment, portable welders, as in Fig. 4, can be used. Usually the parts to be welded are located and clamped in jigs, which can be stationary or movable to provide utmost convenience to the operator. Portable welders can be operated by air, by hand, or hydraulically.

By means of sequencing timers and controls, the complete operation of a portable welder can be made automatic. Operating speeds as high as two to three hundred spots per minute are obtained. The gun is electrically connected to the

transformer by special water-cooled extra-flexible cables. Air-operated guns are less expensive than the hydraulic types. However, for given welding pressures, air-operated guns functioning at 80 pounds per square inch air pressure are heavier than hydraulic types which work on 1000 pounds pressure. Because the weight of the gun is of prime consideration, the hydraulic type has the greatest adaptation. Air-hydraulic boosters or intensifiers provide the hydraulic pressure from the factory air-supply line. Hand-operated welders are seldom used and are confined to light gages. Stick or push guns are frequently used for welding light sheets to heavier plates or where back-up plates are provided in the fixture. Adaptations of this are pry-bar fixtures that provide leverages, thus greater pressures.

Stored-Energy Welders

To reduce the peak, single-phase loads imposed by the resistance welder on the power system and because of the enormous expansion in aluminum welding, stored-energy resistance welders that operate from three-phase lines have grown rapidly in popularity. There are two types. In the electromagnetic, energy is converted from three-phase to direct current and fed into a special welding transformer, and through proper controls, into the work. In the electrostatic type, capacitors are charged from the three-phase lines after conversion to direct current. The capacitors are discharged through the welding transformer to the work, thus making the weld. In addition to the advantages of lesser demand from the line and taking in balanced three-phase load of high power factor, stored-energy welders produce a quality of workmanship and uniformity that cannot be duplicated on other types of equipment. Stored-energy welders appear in both rocker-arm and press-type forms. Air operation is used almost exclusively, because of its greater flexibility.

Seam Welders

When a line weld is to be made, such as the longitudinal lap weld in a cylinder, a seam welder is used. This machine basically is similar to a press-type spot welder. The welding electrodes are replaced by welding wheels with bearings and a drive mechanism. One or both wheels can be driven by friction on its periphery from a driving wheel, or one wheel can be gear driven. Air is invariably the pressure medium of standard seam welders. The wheels are rotated at speeds ranging from two to thirty feet per minute depending on the nature of the work. During the weld, current may flow continuously, or it may be in the form of interruptions (usually two to six cycles of current flow followed by two to six cycles of "off" time, these figures based on a 60-cycle system). These current applications are provided by ignitron tubes, which are in turn controlled by grid-controlled thyratrons. Seam welders can be of the longitudinal type, or of the circular type in which the wheel shafts are parallel with the arms. They are also furnished as universal machines, in which the upper head swivels 90 degrees and separate lower arms are provided; or both lower arms can be integral and swing from one position to the other.

Seam welders appear in many forms and have many special applications. The upper wheel may be idling and the lower wheel replaced by a platen or table with a flat die on which the work is located and clamped. This table is moved by motor drive or hydraulic cylinder much the same as a planer. Or, the table can be stationary and the upper wheel moved over the work similar to a shaper. Several simultaneous seam welds can be made if the single wheel is replaced by several wheels.

A seam welder can be controlled to make a row of spots spaced several inches apart. In the case of interrupted control, the spots can be so closely spaced that they overlap, thus making a continuous water-tight, gas-tight joint.

One of the latest developments in seam welding and one destined to find wide application is the use of direct current from dry-type rectifiers. This is particularly applicable to thin gages at high speed. At a welding speed of 50 feet per minute, the alternations in a 60-cycle line create, in effect, a succession of spots that do not overlap. At this speed, this results in only 12 spots per inch of weld, which is not a gas-tight joint on thin gages; hence, the use of direct current, which produces a continuous weld instead of a series of spots.

Flash Welders

Butt welders are of two kinds, upset and flash. The machines for each are essentially similar. In fact, some machines can be used for both flash and upset welds. An upset weld is made by clamping the two rods or bars into the dies of the machine. One end is held stationary, while the other is movable towards it. An upset welder is much like a press welder laid on its back. Actually, however, the details of design differ considerably. After the abutting ends of the work have been clamped in place, first pressure is applied, and

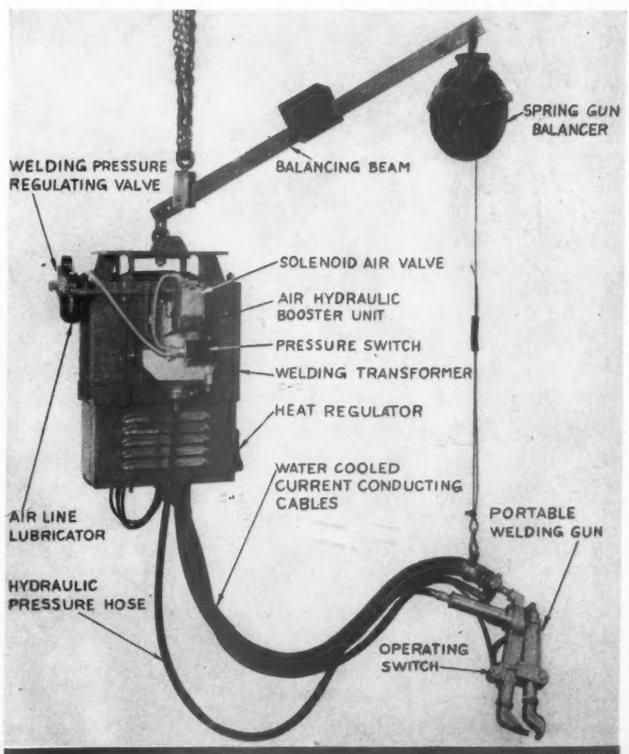


Fig. 4—*Work not readily mobile is welded with this type of portable welder. The weight of the equipment involved has been ingeniously counterbalanced to facilitate handling of gun.*

Spot welding is now an indispensable feature on most production lines.

then the current. Because the joint between the two pieces offers the highest electrical resistance, the greatest heat is generated there. When the heat becomes high enough to render the metal plastic, it collapses under the pressure, the current is cut off, and the weld has been made. Pressure application can be by hand lever, air, hydraulic cylinder, spring, or weights. By various combinations, the action can be completely automatic, resulting in high production.

In a flash welder, the work is clamped in place as in the upset welder. However, the abutting ends are not in contact, or if they are, no pressure is applied. They may merely touch one another. Current is then applied. The movable platen is operated either by a simple lever or compounded with toggles, depending on size and capacity. If the work pieces are not in contact when current is applied, then they are brought together lightly by the hand lever. The open-circuit voltage across them, as in practically all resistance-welding processes, is from two to twenty volts. Because at this light contact only one or a few points touch, the current flow causes them to be blown or "flashed" out, much as a fuse. This leaves a gap between the surfaces and as the pieces are pushed closer together, additional high spots touch, repeating the performance until the entire abutting surfaces are arcing and flashing. As the metal burns away in this manner, new metal is fed in, thus continuing the flashing process. As this flashing proceeds, the heat of the resulting arc flows into the work piece. When the heat has progressed deeply enough, the current is suddenly interrupted, and instantaneous pressure applied. Note, however, that no pressure is used during flashing. The work pieces are merely fed together to maintain the flash. The rate of feed is important and delicate. If it is too slow, the arc cannot be maintained and the flash will stop. If it is too fast, the arc will be snuffed out and the pieces will "freeze" together.

The principal advantage of flash welding over upset welding is in the fact that during the flashing period all surface impurities in weld area are blown out; therefore no dirt, scale, or inclusions not present in the inner composition of the metal can be included in the weld. When the burr left by the weld is removed, no trace of the weld remains except by metallographic examination. Flash butt welds made in low carbon steel (SAE 1010) can be subsequently drawn or formed the same as the original metal. Steels with high carbon content as well as alloy steels can be flash welded, but subsequent heat treatment may be necessary.

Other Uses of Resistance Welding and Its Future

Other miscellaneous uses of resistance-welding machines embrace such applications as brazing and heating. Brazing is accomplished by means of high-resistance electrodes, such as carbon, tungsten, molybdenum, etc., holding the work to be brazed with the heat being generated both in the work itself and also in the electrodes and radiated into the work.

Electric resistance heating is often economically desirable for heating the ends of bars for forging, upsetting or bending.

Resistance welding has contributed more to mass production and cost reduction of metal fabrication than any industrial process in the past twenty years. The introduction of the Ford Model A car was the first large-scale application, following which its use quickly spread throughout the automotive industry and other industries.

Today, time is short, and we can't wait for redesigns that would utilize resistance welding to the maximum advantage. This will be a further development for peacetime aircraft production. Today's giant bombers and airliners have over a million rivets that will be replaced by spot welds.

Resistance Welds with Electronic Control

A tiny snowball may loosen a terrific avalanche, having irresistible power for destruction. The minute electron not only releases tremendous electrical power for rapid welding construction, but also controls it precisely, saying in effect; so much power here, so much there, now stop, now go, finished, and release. Electronic control has not only arrived, but through its exact effectiveness and easy manipulation, is going all out and leading the way.

T. H. LAWSON
Electronic Sales Engineer, Westinghouse Electric & Mfg. Company

THE SECRET of the success of resistance welding has been the startling increase in the exactitude with which the welding process is controlled. Electronic control has provided the means whereby this exactitude has been furthered to its present high state. Mechanical controls for resistance welding were adequate for the crude mild-steel welds made a decade ago. Now, current conditions require not only precise mild-steel welds, but also welds for aluminum, bronze, brass, copper, and many steel alloys made with rapidity and exactness. As is generally the case with an entirely new device, industry was hesitant to adopt electronic control for resistance welding. However, the electronic control has performed so well that it swept aside its initial handicap of unfamiliar apparatus and higher first cost, as is indicated by the fact that its use has increased twentyfold in ten years.

The first resistance-welding machines were controlled entirely by mechanical means. The operator manually closed the power circuit to the welding transformer and applied the pressure to the work as well. He estimated the correct duration of current flow for a satisfactory weld. The process was limited, therefore, to the coarser sheet-steel structures where severe electrode marking, warping, blacking, and scaling could be tolerated.

Magnetic contactors, pressure cylinders, and mechanical timers were employed next with the expected improvement in weld quality and increase in production volume. With these devices, which accelerated welding practices, positive application of current was made for an accurately predetermined interval. While the welds with these controls proved satisfactory in mild steel and some of the commoner steel alloys, they were inadequate for many of the non-ferrous metals and alloys, and some of the modern steel alloys also. This was largely because of lack of precision in timing the start and finish of the welding current application and lack of precise pressure control.

Critical Welding Demands Led to Electronic Control

Within the last few years, resistance welding has become, of a necessity, a precision process. It has been extended to a wide variety of modern alloy metals, such as stainless steel, brass and bronze, and aluminum. Electronic control is being specified by the user on most new resistance welders, and also for bringing existing equipment up to date. This device eliminates the shortcomings of the mechanically controlled resistance welds in that the quantity of current to the weld can be precisely determined in addition to limiting accurately the duration of the application of the current. These factors, together with definite pressure control, especially in certain non-ferrous alloys, determine the quality of the weld.

One of the principal factors that delayed the general acceptance of electronic control for resistance welding was lack of complete reliability of the equipment through short-lived electronic tubes and other associated equipment. In the past several years, however, the increased life of the ignitrons and the use of heavier, more rugged resistors, capacitors, potentiometers, transformers, etc., have achieved an excellent consistency of operation.

Resistance welding is accomplished by passing a heavy current through two or more pieces of adjacent metal clamped between electrodes of copper or copper-alloy, which

The ease of adjusting the automatic, fully electronic weld timer is demonstrated by the author. The disc with pins arranged about the circumference, seen in the background, is the heart of the partially mechanical, synchronous control for a seam or spot welder that is discussed at length in the text.

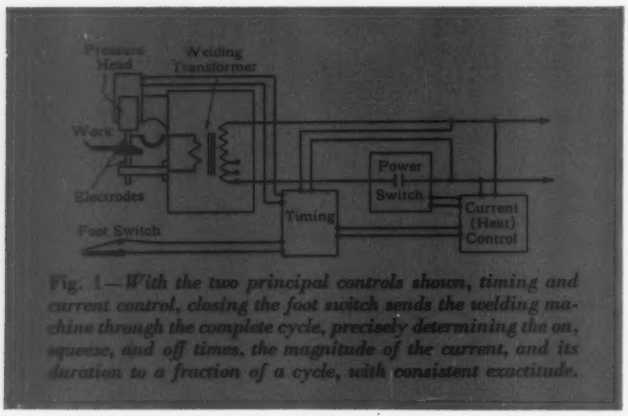


Fig. 1—With the two principal controls shown, timing and current control, closing the foot switch sends the welding machine through the complete cycle, precisely determining the on, squeeze, and off times, the magnitude of the current, and its duration to a fraction of a cycle, with consistent exactitude.

apply pressure and conduct heavy current to the junction. The ohmic resistances of the metals and of the surfaces in contact develop heat, fusing the metals together. The heavy currents are supplied to the metal to be welded from the secondary of a high-current transformer. The welding operation is tantamount to short-circuiting the secondary through the metal as shown in Fig. 1. Accurate control of the following functions must be maintained to prevent the burning or warping of the metal and sticking of the electrodes: (1) the amount of current passed through the work, (2) the time this current is allowed to flow, and (3) the time and amount of electrode pressure.

The control required to perform these functions satisfactorily can be divided into broad classifications as follows:

1. Single-phase a-c welding
   a. Non-synchronous
   b. Synchronous
2. Three-phase stored-energy a-c welding
   a. Magnetic
   b. Capacitor or electrostatic

Single-Phase A-C Control

A non-synchronous control permits random closing of the single-phase power circuit by pushbutton, mechanical timer, or foot switch. Such random operation results in momentary abnormal current peaks dependent in magnitude on the part of the wave at which the circuit is closed, as shown in Fig. 2 (a). These uncontrolled fluctuations in current cause changes in the amount of heat supplied to the weld during

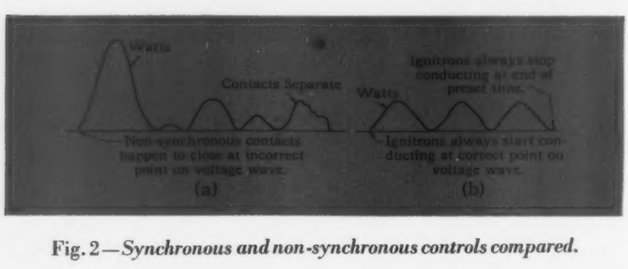

Watts
Contacts Separate
Non-synchronous contacts happen to close at incorrect point on voltage wave.
(a)
Watts
Ignitrons always stop conducting at end of preset time.
Ignitrons always start conducting at correct point on voltage wave.
(b)

Fig. 2—*Synchronous and non-synchronous controls compared.*

(a)—The closing of the contacts at an incorrect point on the voltage wave causes irregular application of power to the weld with resulting poor welds and surges of heavy power demand on the source of supply.

(b)—With electronic control, power demands are uniform and always of the same order of magnitude due to the firing of the ignitrons at the same point on the voltage curve. Further, the ignitrons always stop conducting precisely at the end of a preset time, making for maximum control of weld quality under repetitive-operation conditions.

the first few cycles. Hence there is undesirable variation in weld quality, especially on short-time welds of a few cycles. On longer welds, say, up to 20 or 30 cycles, the transient condition is a small percentage of the total energy used in making the weld, and therefore does not greatly affect the quality.

A synchronous control closes and opens the power circuit at the same point on the voltage wave for every weld so that high transients are eliminated, Fig. 2 (b), and more consistent welding obtained. There is no ironclad rule when to use synchronous control or when to use only the non-synchronous controls. However, certain general recommendations can be followed:

1—The shorter the weld time the more necessary synchronous control becomes. Non-synchronous control should not be used for welds shorter than about four or six cycles, if consistent results are expected.

2—Certain materials difficult to weld, such as aluminum, brass, and stainless steels require synchronous control.

3—When highest quality welds are required, either for uniform spot size and strength, or good metal surface appearance in any metal, synchronous control is used.

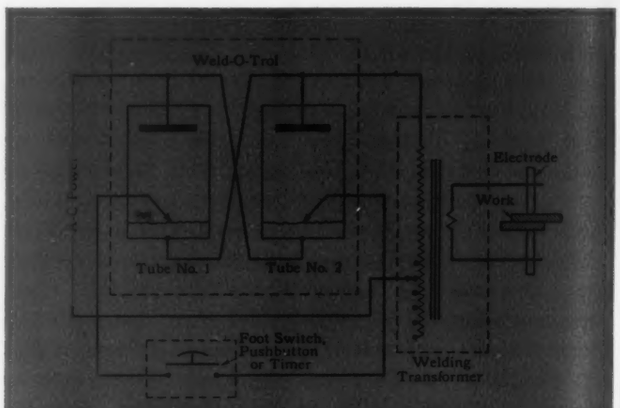


Fig. 3—Two ignitrons used in full-wave rectifications. The control switch is placed in the special igniter circuit of these heavy-duty mercury-vapor rectifiers for exact current control.

4—Non-synchronous control should be used principally for mild steel and long-time welds when minimum first cost of equipment is more important than highest weld quality.

Non-Synchronous Control

An electronic control in widespread use for non-synchronous welding consists of a single-pole ignitron tube "contactor" used to make and break current as high as 8000 to 10 000 amperes rapidly without arc, noise, or moving parts. It is known as Weld-o-trol, and is applicable (within its rated limits) to any a-c resistance-welding machine as the device that connects the primary of the welding-machine transformer to the a-c line.

The heart of the Weld-o-trol, and all other electronic controls that handle the heavy current of a-c resistance welders, is the two ignitron tubes. These are shown schematically in Fig. 3. An ignitron is a heavy current-carrying mercury-arc-rectifier tube with a special igniter (or "spark-plug" in the trade parlance) firing device. Each tube passes alternate half cycles of current to the primary of the welding-

machine transformer as long as the ignitron circuit is energized. Selection of ignitron-tube size is based on the maximum current drawn and the duty cycle imposed.

One advantage of the ignitron over mechanical contactors in resistance welding is the extremely fast speeds at which it can operate. Having no moving parts, it readily makes and breaks currents of several thousand amperes 600 times per minute. Also of great importance is the accuracy with which it can be timed and the fact that the amount of current passed by the tube can be smoothly controlled. In addition, when ignitron tubes are used to carry the current to a resistance welder, in either non-synchronous or synchronous control, an electronic current (heat) control device can be used to allow proper welding of various kinds and thicknesses of metals.

Heat control uses two thyratron tubes to make or break the igniter or firing circuit of the ignitron power tubes. This control of the current passed by the ignitron is achieved by

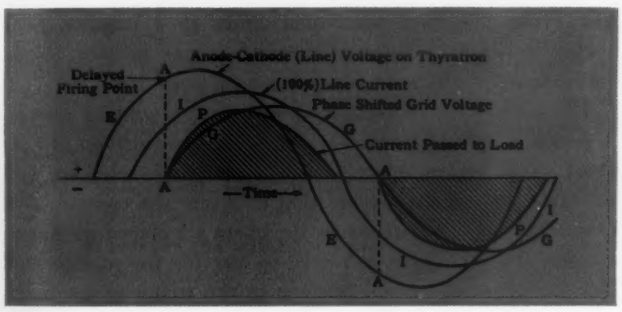


Fig. 4—*Method of limiting load current by phase control.*

Assuming, for the simplicity of illustration, that the critical grid voltage of these thyratron tubes is along the zero axis, when the a-c voltage, curve *G*, applied to the grid is positive the thyratron tube will fire. When the voltage on this curve *G*, as applied to the grid, is negative the thyratron tube will not fire. Therefore, by shifting position of the voltage curve *G*, with that shown on line voltage, curve *E*, the thyratron can be made to pass current at any point on voltage wave, *E*. For example, if curve *G* intersects the axis and goes positive at a point *A* in the cycle, the thyratron fires at this point closing the igniter circuit of the ignitron tube and allowing current to flow as shown by the shaded area under curve *P*. Thus by shifting of the thyratron grid voltage *G* with respect to line voltage *E* the amount of current passed by the ignitron tubes is smoothly and accurately controlled.

shifting the phase of the thyratron grid voltage with respect to the line voltage. This action is shown in the curves in Fig. 4. This grid voltage is the resultant of a resistor-reactor circuit. By varying the amount of resistance in the circuit by means of a potentiometer the phase position of grid voltage with respect to the line voltage can be shifted. This is shown in the schematic grid-voltage vector diagrams, Fig. 5. Various degrees of heat control by this method are shown in Fig. 6.

The Weld-o-trol and heat control accomplish one of the primary control functions needed in good resistance welding, that of applying and controlling the magnitude of the current to the welding transformer. There still remains to be controlled two other primary functions requisite to good welding: the duration of weld current and the electrode pressure and sequence.

Some resistance welders use manual- or motor-operated electrodes with cams to start and time the weld current. On

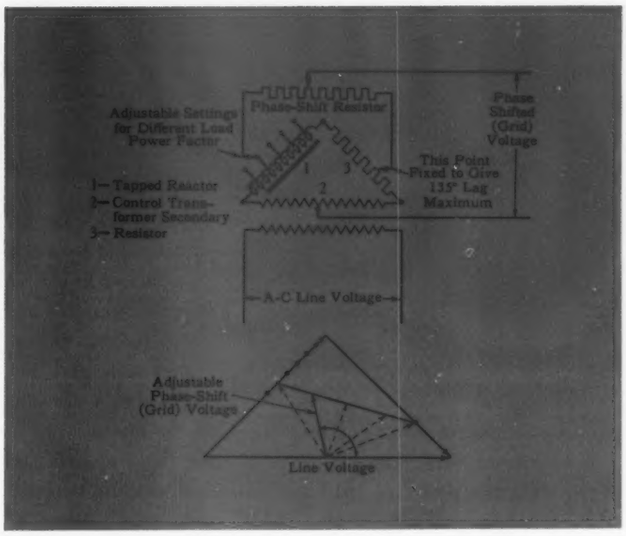


Fig. 5—*Schematic and vector diagrams of the method of phase shifting of the grid voltage by means of a variable resistor.*

such machines automatic weld timers are not required. When air- or hydraulic-operated electrodes, with solenoid-operated valves are used, weld timers are employed to time the duration of current flow and also to time the electrode sequence. Electrode pressure is determined by regulators normally a part of the welding machine proper, rather than a function of the control device.

The nerve center of an electronic automatic weld timer consists of one or more small thyratron tubes acting to operate small, lightweight, fast-operating relays which in turn control the primary-line contactor or Weld-o-trol. The thyratron is a three-element electronic grid-control tube, used to control other units handling heavy currents. In the case of the Weld-o-trol it energizes the igniter circuit of an ignitron, and in the case of a magnetic contactor it energizes the coil. The relays in the weld timer also control the solenoid valve in the welding-machine head. Normal timing intervals of $^3/_{60}$ to 6 seconds are obtained by adjusting the resistance in a resistance-capacitor time-delay circuit applied to grids of the thyratron tubes. Any or all of the following

Five critical welds in a small assembly for circuit breakers. Affording electrical and mechanical security, welding facilitates mass production.

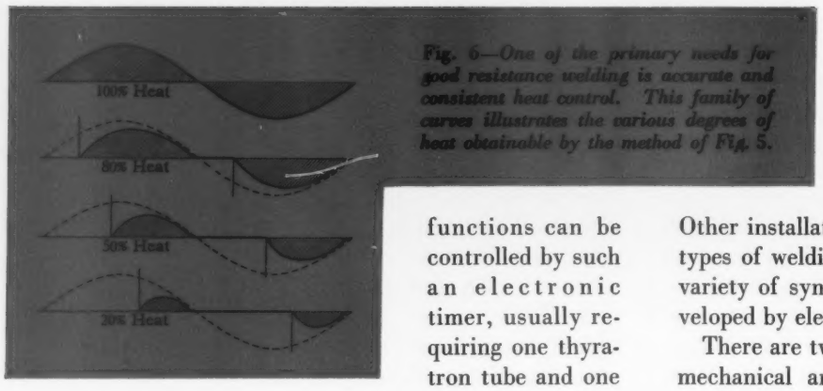


Fig. 6—One of the primary needs for good resistance welding is accurate and consistent heat control. This family of curves illustrates the various degrees of heat obtainable by the method of Fig. 5.

functions can be controlled by such an electronic timer, usually requiring one thyratron tube and one relay with accompanying adjusting potentiometer for each function.

1—Squeeze time: The duration of time from application of the electrode pressure until application of welding current.

2—Weld interval: The total "heat" and "cool" times, or total welding cycle, when welding by pulsation method. In pulsation welding, current is applied to one spot in a series of spaced, short periods, (from a fraction of a cycle to ten or more cycles), the length of the individual period depending on thickness of material, type of weld, and other factors. The pulsation method is used to avoid excessive heat on the external surface of the metal while maintaining welding temperature at the juncture of the metals to be welded. Excessive surface heat causes sinking of the electrode into the plastic metal with resultant pits or craters in the metal surface at the weld, and rapid deterioration of the electrode. The "heat" time is the period during which current is applied, and the "cool" time is the interval between applications of current.

3—Hold time: The time that pressure is maintained at the electrodes after the current is cut off.

4—Off time: The time, in repetitive welding, that the electrodes are separated from the work piece.

A complete timing cycle is shown diagrammatically in Fig. 7. An automatic weld timer to perform all of these functions is contained in a cabinet only 12 inches by 17 inches by 12 inches deep.

Synchronous Control

The term, synchronous control for single-phase welding, generally applies to several combinations of power tubes and control elements for both spot and seam welding. In all cases the control is arranged so that the ignitron tubes cannot fire ahead of the zero point on the supply-current wave. In addition, a weld-timing circuit is incorporated on all synchronous controls (normal range of time 1/60 to ½ second), and therefore, the weld-time function need not be controlled by a separate device as outlined for non-synchronous control. However, the order of sequence of the electrodes is handled by a small electronic sequence-timing panel as a unit separate from the main synchronous control. The construction and operation of the sequence panels used in conjunction with synchronous controls are identical with the non-synchronous automatic weld timer, except that the weld-time feature used in the latter is not required.

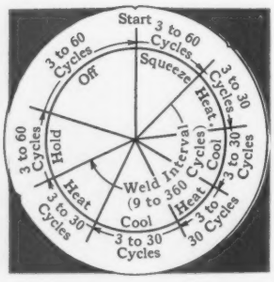


Fig. 7—Typical welding cycle using an automatic weld timer.

Spot- and Seam-Welder Types

Many synchronous controls for spot or seam welding are installed for the single purpose of doing a specific production job. Other installations require a flexibility of application for all types of welding and all kinds of materials to be welded. A variety of synchronous control combinations has been developed by electrical manufacturers for most applications.

There are two types of seam-welding timers, one partially mechanical and the other fully electronic. The partially mechanical seam-welding control has chain or disc timing. In the disc type, pins inserted in the synchronously driven disc pass through a magnetic field, and this magnetic field variance, by means of an electronic device, controls the number of cycles the current flows and the number of cycles the current is off. A pinhole is provided in the disc for each half cycle, affording control accurate to a fraction of a cycle. A portion of one of these discs can be seen in the background of the author's picture on page 109.

The chain type of control operates on a contact system. A series of spaced metal buttons on a chain driven at constant speed makes contact with a stationary element and provides the timed impulses that motivate the controls. Between the metallic buttons on the chain are placed insulating spacers. The timing is achieved by varying the number and the spacing of the metal buttons in the string of insulating discs, giving any number of possible combinations.

Thus, by either system, while work is rolling through seam-welding electrode wheels, a stitching effect is simulated. Heat is applied intermittently, and a row of spot welds made. This operation continues as long as the operator keeps the control running, making a seam weld of any desired length.

The completely electronic type of seam timer does not have the mechanical disc- or chain-timing device. It is entirely electrically operated, and in addition to seam timing, this unit is arranged to time straight spot welding and pulsation welding. This flexibility of the fully electronic control permits quick and accurate conversion to spot or pulsation welding with a minimum of effort. It is not necessary to insert pins or buttons as in mechanical timing devices. To change timing, it is merely necessary to change the timing dial to the desired number of cycles on and off. The adjustment for spot or pulsation welding is readily accomplished with electronic control; whereas the mechanical controls are made only for seam-welding operations.

Energy Storage Control

In single-phase welding the energy is taken direct from the a-c line through a transformer. The welding transformer secondary is essentially short-circuited. Thus the load imposed on the single-phase system consists of many high current peaks of short duration and low power factor.

To reduce demand peaks, and to provide other desirable features not found in straight single-phase resistance welding, methods of

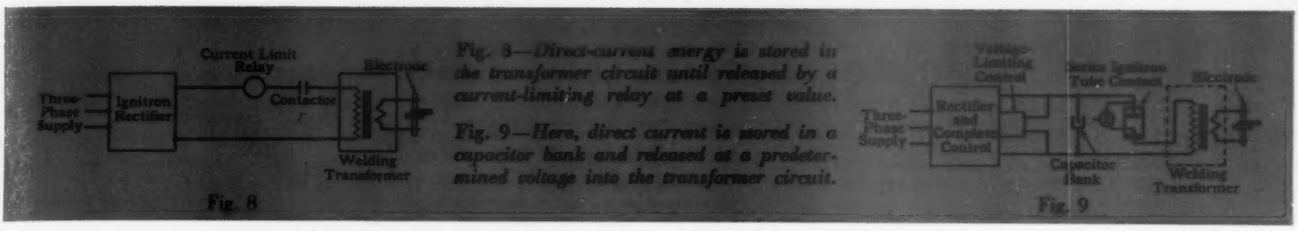


Fig. 8

Fig. 8—Direct-current energy is stored in the transformer circuit until released by a current-limiting relay at a preset value.

Fig. 9

Fig. 9—Here, direct current is stored in a capacitor bank and released at a predetermined voltage into the transformer circuit.

welding with stored energy have appeared. This method of welding has been introduced in the United States within the past three years, and is used at present primarily for welding aluminum. Its basic principle is to draw energy slowly from a three-phase line and store it until the weld is made. In some cases, this energy-storage method has reduced peak kva 80 per cent.

The two types of energy-storage control are the magnetic type, which stores energy in the iron core of the welder transformer, and the capacitor type, which stores energy in a bank of capacitors.

In the magnetic type, shown schematically in Fig. 8, direct-current energy is stored in the magnetic circuit of a transformer. Power is taken from a three-phase line and rectified by ignitrons, which operate solely as rectifiers. The electrodes close and apply pressure to the work, and the contactor is closed. The current then builds up over a period of several cycles in the primary of the welding transformer. When it reaches the point for which a current-limiting relay has been set, the relay opens the contactor. The rapid decay of current in the welding transformer primary causes a high inductive kick (current) in the secondary. It is this current that makes the weld. If the current-limiting relay is accurate, an identical amount of current will be produced in the weld every spot, regardless of fluctuations in line voltage.

In the capacitor type, Fig. 9, energy is taken comparatively slowly from a three-phase line and rectified to furnish direct current to charge a large capacitor bank. Here, instead of a current-limiting relay, a predetermined voltage setting is reached. The d-c charge voltage can be set from 1000 to 3000 volts, and maintained on the capacitor bank by a trickle-charge scheme until the operator presses the initiating switch to make a weld. This contact allows the series ignitron used as a line contactor to fire, discharging the capacitor bank into the welding transformer and giving one undirectional current pulse for each spot. The current pulse is the same for each spot if the same capacitance and voltage setting are maintained, regardless of fluctuations of the line voltage.

A-C Control vs. Energy Storage

Single-phase welding is being used on both ferrous and non-ferrous metals, including aluminum, whereas energy storage is used primarily on aluminum. The first cost of the single-phase control is much lower than that of the energy storage. Single-phase control has been developed over an extended period and is simpler in design and construction. Resistance-welding operators are more familiar, in general, with a-c control.

In spite of its comparative newness, energy-storage control has proved its advantages. It provides a balanced three-phase load instead of single phase, with much lower peak kva demands, and with improved power factor. Smaller conductors can be used for power supply, permitting lower wiring cost and greater flexibility in rearrangement of equipment. More consistent results in welding aluminum for the aircraft industry are claimed because: (a) the weld is made with measured energy, (b) line-voltage variation does not affect the energy applied to the weld, (c) electrode "pick-up" is less with accompanying longer electrode life, (d) forging action can be applied to heavier gage welds helping to prevent cracks in the metal.

Whereas single-phase control is well developed, the development of energy-storage control is far from completion. Its present more complicated design, quickly developed because of the need for control in the aircraft industry, will undoubtedly be greatly simplified, and its first cost reduced in the future. When this has been achieved, energy-storage welding will make further advances in general industry.

Resistance welders as a group are efficient but colorless. The exception is the flash welder, shown here, which approaches the arc welder for spectacular action. Photograph courtesy The Cleveland Pneumatic Tool Co.

Balancing the Tin Budget

Notions of self-sufficiency have been sharply revised in recent months. The United States found itself in the uncomfortable position of being the world's largest user of tin but without any ore of its own or even any smelter to produce tin from foreign ore. The fault, however, is not in having a false idea but in being unable to accommodate to the true condition. Unnecessary uses of tin have been lopped off, worthy substitutes developed, and schemes of permanent value devised for decreasing the tin necessary on other products, so that essential needs will be served.

TIN HAS become a precious metal. The expression "It sounds 'tinny' " no longer marks contempt. Engineers are busy devising substitutes or lessened use for tin. Millions of dollars are being spent on new plants to save tin. Silver is even replacing it for some uses. Until that eventful Sunday last December we took tin for granted, threw away old tooth-paste tubes and tin cans with that fine disregard for saving materials so characteristic of Americans. Now we are painfully aware of tin's vital although inconspicuous place in our scheme of things, and, for the most part, must learn to get along without it.

As to tin, the United States is a "have not" nation. This country normally consumed a third of the world's total output, but produces virtually none of it. In 1939 a trivial 34 tons* of tin were mined in this country, and none was smelted. This while the remainder of the world was mining 173 000 tons of tin, of which the United States was using 67 000 tons. Tin-bearing ores are scattered throughout this country and Alaska, but mostly they are low grade, and their extent is not fully known. Certainly there is no possibility that the United States will be self-sufficient in tin within several years, if ever. We must get along with less.

The best tin ore is found in the Far East. A narrow strip of territory, mainly along the west side of the Malay Peninsula, from Rangoon to Singapore, comprises about 42 per cent of the world's production. This and the output of Dutch East Indies, Thailand, Burma, and Indo-China—now all Japanese controlled—comprise two thirds of the world total. Furthermore, this Far East tin ore is the highest grade, is most easily mined, and is simplest to smelt. The Dutch East Indies ores are smelted in ordinary reverberatory furnaces to produce 99.9 per cent pure tin. Thus, Eastern tin is cheapest, aside from the much lower labor cost. As evident from table I, the largest supply of tin left to the United Nations is in Bolivia. Bolivian ores must be mined, at an elevation of 10 000 feet, where there is a dearth of fuel, and are not as rich as Malayan ore.

The smelter situation is even worse. The only important tin smelters are in ex-British Malaya, China, Holland, Dutch East Indies, and England. Smelters representing three fourths of the world output are in Axis hands, as table II shows. The United States is faced with the uncomfortable fact that the only tin available to it in quantity must come from ores that have to be shipped in boats badly needed for other purposes, through hazardous waters to England, and the tin reshipped to these shores.

To correct this situation partially, a smelter has been built with Reconstruction Finance Corporation funds at Texas City, Texas, to use the lower grade Bolivian ores. This smelter was intended to produce initially 18 000 tons per year, but eventually will produce three times as much. The best Bolivian ores go to England under a contract that has a period of several years yet to run.

Revising Our Tin Needs

There is no single substitute for tin. In the scramble to reduce the tin requirements almost every form of saving is being used: elimination of some products using it, reduction of tin in other products, and complete substitution of some other material. Every form of engineering ingenuity has

Table I—World Mine Tin Production (1939)

	Tin Content	
	Long Tons	Per Cent of Total
Malay States	51 725	30.0
Dutch East Indies	27 755	16.0
Bolivia	27 211	15.7
Thailand (Siam)	17 325	10.0
China	10 422	6.0
Belgian Congo	9 663	5.6
Nigeria	9 427	5.5
Burma	4 500	2.6
Australia	3 500	2.0
United Kingdom	1 710	1.0
Japan	1 700	1.0
United States	34	0.02
All Other	7 728	4.5
Total	172 700	

Table II—World Smelter Production of Tin (1939)

	Long Tons	Per Cent of Total
British Malaya	81 536	47.7
England	37 400	21.8
Dutch East Indies	14 788	8.7
Netherlands	14 600	8.6
China	10 850	6.4
Australia	3 300	1.9
Belgium	2 124	1.2
All Other	6 102	3.7
Total	170 700	

Table III—Uses of New and Reclaimed Tin in the United States (1939)

	New		Reclaimed
	Long Tons	Per Cent of Total	Long Tons
Tin plate	36 640	55.5	0
Terneplate	317		1 137
Solder	9 578	14.3	7 701
Babbitt	3 850	5.8	1 598
Bronze and brass	3 385	5.1	3 051
Collapsible tubes	3 507	5.3	0
Foil	2 001	3.0	0
Tinning	2 165		172
Chemicals (other than tin oxide)	167		288
Pipe and tubing	606		0
Tin oxide	651	11.0	359
Type metal	149		990
Galvanizing	1 028		0
Bar tin	1 100		241
Miscellaneous alloys	404		45
White metal	466		42
Miscellaneous	569		221
Total	66 583		15 845

*Tin tonnages are always given in long tons of 2240 pounds.

been manifested, of which only a few representative ones can be given here.

The easiest tin-saving problems occur in those products classified in table II as "other." Production of pewter, jewelry, badges, toys, and novelties using tin has ceased. The tin used in galvanizing can be dispensed with because it is added for spangle only, and does not assist in the corrosion resistance of the zinc coating. The use of tin oxide, principally as an opacifier in vitreous enamels, was declining anyway because other oxides are cheaper and can be readily used. Considerable reduction of tin required for type metal is being effected by greater attention to spillage and other losses, and by melting down of standing type.

Cigarette smokers and candy-bar fans were quickly made aware of the tin shortage by the early disappearance of the foil around the package. Most so-called tin foil actually was lead with a tin coating. Where waxed paper or its equivalent cannot replace the foil, it can be made entirely of lead, or with a much thinner tin coating.

That Old Tooth-Paste Tube

Makers of collapsible tubes for tooth paste, shaving cream, cosmetics, vaseline, food pastes, and so on ad infinitum, rank in the top half dozen users of new tin. These tubes were made by cold extrusion of soft metal, (1) pure tin, (2) lead-tin, (3) tin-coated lead, (4) all lead, and (5) aluminum, which all look alike to most people. Actually a declining percentage of the collapsible tubes was being made of pure tin before Pearl Harbor. (Tin cost about 50 cents per pound, and lead only 8.) Relatively few products, such as eye salves, require an all-tin tube for protection of the product. For most purposes a tin-coated lead tube (a layer 2½ per cent by weight of tin on one or both sides of lead) is fully satisfactory, and a tube of lead with a little antimony and waxed or lacquered is sometimes adequate. Use of all-aluminum was increasing before the shortage, and is expected by some authorities to assume a dominant place in the collapsible-tube business when aluminum is plentiful.

That worthless-looking crumpled tooth-paste or shaving-cream tube you return to the drug store does, very definitely, find its way back into circulation. Not, however, as another collapsible tube, but perhaps as a part of the bearing of a new motor. The collapsible-tube makers formed a cooperative tin-salvage organization, with plant located in New Jersey, to receive all the used tubes from the entire United States. At this plant the tubes are sorted by hand into the five classifications, which are separately melted down for use by industries that can use salvaged metal. This salvage operation is recovering more tin than the collapsible-tube industry now uses.

Bronze Has Used Little New Tin, Will Use Less

Although bronze accounts normally for about 6500 tons of tin, only about three fifths of this was virgin metal, the remainder being obtained from salvage. The ordinary cast bronze, used for valves, pressure fittings, etc., is 85 per cent copper, 5 per cent tin, 5 per cent zinc, and 5 per cent lead, and can be produced for a long while without much new tin. With some redesign this bronze can be made to do for other types of bronze in which the tin content is higher. In the bronze for some types of bearings—80 per cent copper, 10 per cent tin, 10 per cent lead—tin cannot be safely eliminated, but can be reduced. Bearings for steel-mill rolls, for propeller shafts, hoists, etc., on shipboard, and other places where temperatures are not high, are being made of plastic-impregnated fiber of the Westinghouse Micarta type, oftentimes with greatly increased life. Bronze, other than for bearings, is for some service being replaced by copper-base alloys of equal strength and corrosion resistance, but more difficult to handle in the foundry. The silicon, aluminum, manganese bronzes, and aluminum castings serve for some purposes, but these alloys lack the good machinability resulting from lead in the older types of bronzes. A free-machining tinless bronze would be welcome.

New Babbitts Are Almost Tin-Free

Babbitt, unlike bronze, has only one use—bearings. In 1939 tin requirements for babbitt amounted to 5500 tons, of which one third was reclaimed tin. Most babbitts were of two types, a tin-base alloy (85 to 90 per cent, remainder antimony) or a lead-base alloy (5 to 20 per cent tin, 5 to 15 per cent antimony, remainder lead). The most promising babbitt-tin savers are the arsenic-lead alloys. These consist of from 1 to 3 per cent arsenic, 12.5 to 16 per cent antimony, and 1 per cent or less of tin, and remainder lead. The melting point of this babbitt is higher than either the older lead-base or the tin-base babbitts, and hence requires somewhat more care in its use. The quality of the lead-base arsenic bearings is good, sometimes better, than that of previous babbitts.

Virtually all tin-base babbitts are eliminated, either by changing bearing design to use the lead-base materials with low tin or the arsenic-type babbitts. Many of the predominating lead-base bearings will be changed to the tinless alloy.

New Solders Use Less Tin

Solder presents a real problem to the tin conservationist, and the quantity of virgin metal that goes into it is large. Solder used 9600 tons of new tin in 1939, second only to tin plate. Pure tin has long been used as a solder in the tin-can industry and in other industries for joints required to operate at relatively high service temperatures. Pure tin melts at 232° C, while the so-called 50-50 tin-lead solders (usually 40 to 50 per cent tin) start to melt at 181° C. The tin-can industries have altered their soldering technique and are now using lead-silver solders containing 2 to 5 per cent silver and the remainder lead. These solders start to melt at about 300° C and require soldering temperatures of about 350° C. These higher soldering temperatures, which appreciably increase

shop difficulties, may affect the metals joined. However, the pressure to save some of the tin being used as all-tin solder resulted in a new solder of great promise. This is an alloy of approximately 85 per cent lead, 14 per cent tin, to which is added 1 per cent silver to increase the wetting power. This new solder is being tried on electrical work, where its higher melting point is an advantage. The soldering temperatures are somewhat higher than those required for pure tin, but considerably lower than is needed for lead-silver solder. Admittedly it is more difficult to use, but it has staunch engineering supporters who insist that once the techniques have been mastered, a superior soldering job results.

Where solders containing 40 to 50 per cent tin were formerly used for general soldering many industries are now going to low-tin solders containing from 5 to 30 per cent tin and varying amounts of silver, antimony, and bismuth. The WPB has restricted the tin content in solders to 30 per cent maximum. In complying with this order many solder users have found that the low-tin solders are entirely satisfactory substitutes for 50-50 solders if more emphasis is placed on joint cleanliness and soldering technique.

The largest tonnage item in the consumption of solder was the dip-soldering of automobile radiators, in which about two pounds of tin per radiator were used. Solder was also used to smooth over dents and welded joints before lacquering, to the tune of about one-half pound per car.

Many soldering operations have given way to welding or brazing. Even the two drops of solder used on each incandescent lamp to solder the filaments to the screw base required about 60 tons of solder per year. Spot welding on some lamps, using a smaller solder drop, and changing to lead-silver solder saves substantially all this tin.

Copper brazing in controlled atmosphere is being substituted for some processes previously done by soldering. Brazing with silver solders and Phos-copper using torches or incandescent carbon blocks for heating has replaced soldering in many instances. Phos-copper is perhaps the lowest cost brazing material available and produces excellent joints on non-ferrous materials. A much stronger and higher melting joint is obtained at the same time that tin is being saved. It is doubtful if the electrical industry will ever return to soft solders on many of these applications.

Biggest Saving Is by Biggest User—Tin Plate

Three times as much tin goes into tin plate than for any other single purpose. Reductions here have the greatest significance. By two major tin-conserving actions, about 16 000 fewer tons will be required for 1943's tin plate than for 1941's, a decrease of 40 per cent. This is in spite of a large increase in the number of cans needed for food. Buyers of dog food, beer, peanuts, coffee, etc., are well aware of the prohibition of tin-plate cans for such products. In 1941 beer cans alone accounted for 1600 tons of tin; dog food, 820 tons. Also, some saving is effected by the elimination of small-size cans. Many liquids, such as oil, which require a metal container, are now being supplied in cans made of terneplate,* or of black iron with lacquered surfaces.

This type of economy, however, is limited. We are inextricably wedded to the tin can. To go wholly and immediately to glass containers, as might seem obvious, is impossible. Aside from the problems of greater weight and bulk, and the enormous load it would place on glass-container manufacturers, the most serious obstacle occurs in the food-packing plants. To convert their high-speed canning machinery to glass would require about two years. The intervening decline in output—with millions to feed at home and abroad—cannot even be considered.

The reason for the tin on tin cans is not, as most suppose, to prevent contamination of the food by chemical action with the iron. Only about five per cent of the food in cans must have the protection of tin, such as sauerkraut, a few fruits high in acid content, and some baby foods. The primary reason for the tin coating is to make possible the soldering of the side seam. Indeed, Germany, even shorter of tin than is the United States, applies only a narrow strip of tin along the seam for soldering, but this is an expedient of necessity, not of economics. It is far cheaper and much faster to coat the entire surface than the seam edges.

Fortunately, a new technical development will make it unnecessary to resort to seam tinning. This is the new method of making tin plate. Tin will be deposited on the steel electrically instead of by the hot-dip method.

Tin plate has been made by dipping individual sheets of tin—about half the size of an average desk top—into a cleaning flux, then into melted tin. By this method about 1.5 pounds of tin are used per 100 pounds ofsteel.° By government order, the tin allowed for the hot-dip process has been reduced to 1.25 pounds. Tin applied by hot-dipping is not uniform, varying over the sheet from the equivalent of about one-half pound to nearly two pounds per 100 pounds of steel. Obviously, tin thicker than the thinnest coating is needless. This spread is a manufacturing tolerance that, until the appearance of the electrolytic method,† could not be avoided. By electroplating, tin is applied uniformly and of any desired thickness. Present belief is that the coating provided by one-half pound of tin per base box is adequate for the great bulk of food packing, and most electrolytic tinning lines will operate on this basis. This represents a 60 per cent reduction in the tin required for tin plate, which is really getting somewhere.

Some salvage of tin can be expected from the used tin cans, but not much. Recovering of tin from used tin cans is neither as simple nor as fruitful as that from collapsible tubes. Although the detinning of the scrap from can-making machines has long been done with profit, with used cans the problems of collection, shipment are enormously greater, and the size and number of detinning plants, much larger. To recover one ton of tin requires handling 65 tons of steel, assuming the recovery 100 per cent, which it isn't. But, more to the point, the detinning processes are complex. The

(*Continued on p. 122*)

*Terneplate is steel covered with an alloy of lead and tin in the ratio of about four to one.

°The unit in the tin-plate industry is the base box, which consists of 112 pieces of sheet 14 by 20 inches or 31 360 square inches. The weight of a base box varies with the gage of steel. A general average for tin plate for food cans is about 97 pounds per base box.

†Described in detail in the article by J. Raymond Erbe.

Electrolytic Tin-Plating Lines and Reflowing Methods

Among the many things that must go further these days is tin. The thin layer of tin on tin plate for cans is being spread thinner than ever before. Engineers dug into their bag of tricks and developed ways of applying tin electrolytically. By so doing, two and a half times as much steel is covered as by the old hot-dip methods. Even radio engineering has a hand in the process; in the final finishing the customary bright surface of tin is obtained by slightly reflowing the thin tin layer by heating with high-frequency induction.

J. RAYMOND ERBE
Steel Mill Engineer, Westinghouse Electric & Manufacturing Co.

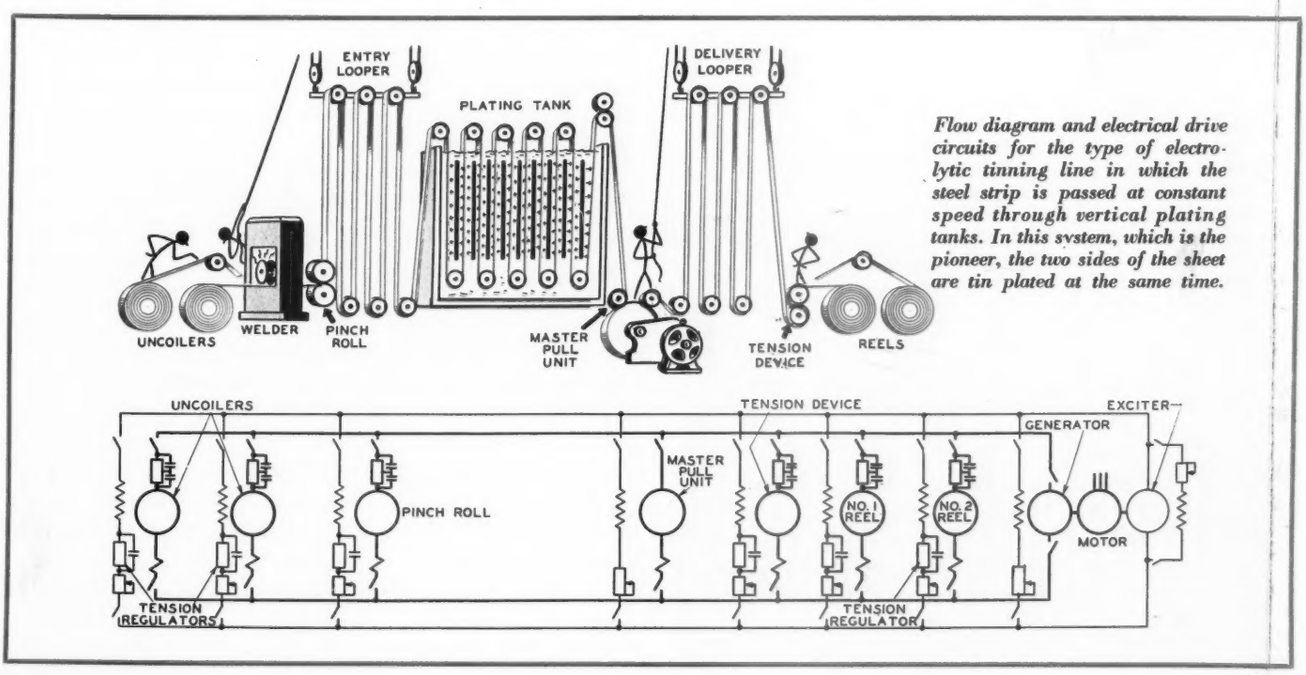
ON DECEMBER 7 the experimental work on electrolytic plating of tin on steel was progressing nicely and in an orderly fashion. Following customary practice steel and container companies were pursuing a program of careful development and testing before launching into expensive full-scale production. The events of that day demanded that methods of electric tinning be brought into operation with all haste.

Electroplating is, of course, an old story to electrical engineers. But electric tin-plating presented a host of new problems of electrical control, power supply, handling, and subsequent finishing of the product. Nowhere before has electroplating been on such an enormous production scale. Some single tinning lines will turn out a sheet, tinned on both sides, three feet wide, at rates up to 1300 feet per minute. This is an area of tin plate equivalent to a football field every 18 minutes.

The several types of tinning lines thus far developed have two basic differences, whether the speed is constant or variable and whether the tanks are horizontal or vertical. In one type of mill the steel moves through the plating tanks at constant speed, and means are provided for accumulating enough slack at the entry end to allow the end of a new strip to be welded on. The other scheme, which in general permits a faster speed of strip, allows the entire line to slow down when necessary to start a new coil. In the line with horizontal plating tanks the two sides of the sheet are tinned separately allowing variation in thickness and even in kind of metal deposited, if desired. In the vertical tank line the sheet is tinned on both sides as one operation and hence exactly alike. To present a clear picture of the problems involved and the associated electrical requirements the two most dissimilar types of lines will be discussed. There will be, of course, variations of each type of line.

The Constant-Speed, Vertical Line

Consider first the constant-plating-speed, vertical-tank line. The steel comes to the electrolytic tinning line in the form of a strip 0.006 to 0.015 inch thick, from 18 to 36 inches wide, and up to three miles long, wound in a tight coil. This coil weighs about 30 000 pounds and is about five and a half feet in diameter. It is placed on one of the two uncoilers at the entry end of the line. The end is squared in the shear, and is then threaded through the welder and the first pinch roll. From the pinch roll it is threaded through the entry looper, the pickling and plating tanks, the rinse tank, and the master pull unit. The strip is fed through the de-



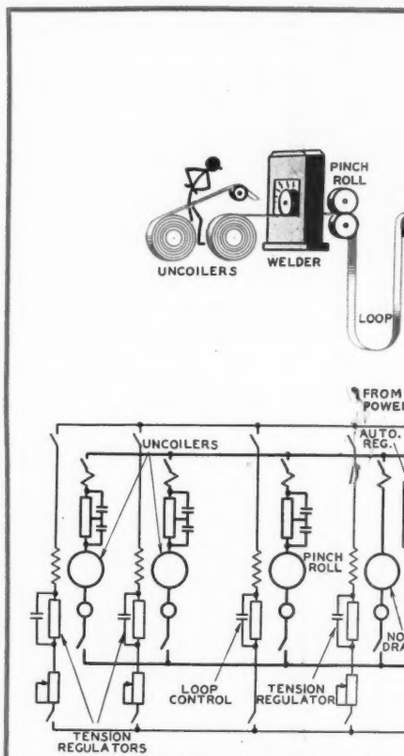
Flow diagram and electrical drive circuits for the type of electrolytic tinning line in which the steel strip is passed at constant speed through vertical plating tanks. In this system, which is the pioneer, the two sides of the sheet are tin plated at the same time.

livery looper, the tension device, the second shear, and entered on the reel. The line is now completely threaded and ready for operation.

As a processing line of this type is operated from a variable-voltage system, the line is started by increasing the generator voltage until it overcomes the internal drop of the line motors so that the strip just starts to move. The plating current and the line speed are simultaneously increased, until the desired operating speed is obtained, by proper manipulation of the plating-generator rheostats. A line of this type usually has a maximum running speed of 500 to 600 feet per minute because it does not seem advisable to have too many strands of strip running faster than this through loopers whose top rolls are at times 30 to 35 feet above the bottom rolls.

With the line running we can examine each individual unit to determine what it must do for satisfactory operation. The uncoiler motor now acts as a drag generator, the steel strip being pulled from the coil against the resistance of the drag generator by the entry pinch roll. To prevent the uncoiler from over-running the pinch roll and allowing slack to accumulate, which might cause a cobble or tangle, a tension regulator is used to maintain a light back pull on the strip. Such a tension regulator operates on the field of the uncoiler drag generator to maintain a constant armature current. In so doing it also serves a second function, that of automatically compensating for the decreasing diameter, i.e. increasing speed, of the uncoiler.

Both of the loopers, as shown, consist of several bottom rolls in a fixed support and several top rolls in a movable support. This movable support is counterweighted. The amount of tension in the strip while passing through the plating and rinse tanks is determined by the counterweights. The purpose of the looper is simply to provide a means of accumulating slack in the strip to be used when changing to a fresh coil. When the strip is first started through the line the field of the motor driving the entry pinch roll is weakened, so that the roll runs about one-fifth faster than the strips through the main components of the line. In this manner the entry looper accumulates surplus strip so that the top rolls are nearly at the top of their travel. When this has been accomplished the pinch roll is then driven in synchronism with the remainder of the plating line.



In this type of tinning line the steel stri welded on. This line is high-speed operat

The plating current is manually adjusted to produce the desired coating weight. In this type of line the anodes of cast tin are supported vertically between the vertical passes of the strip. The negative bus of all plating generators is connected to the contact rolls shown at the top of the plating tank. The positive terminals of the plating generators are connected either to individual anodes or to several anodes in parallel. The plating current can be supplied from either a low-voltage, high-amperage, direct-current generator or a dry-type rectifier such as the Rectox (copper oxide). Both methods are being used on lines now being built.

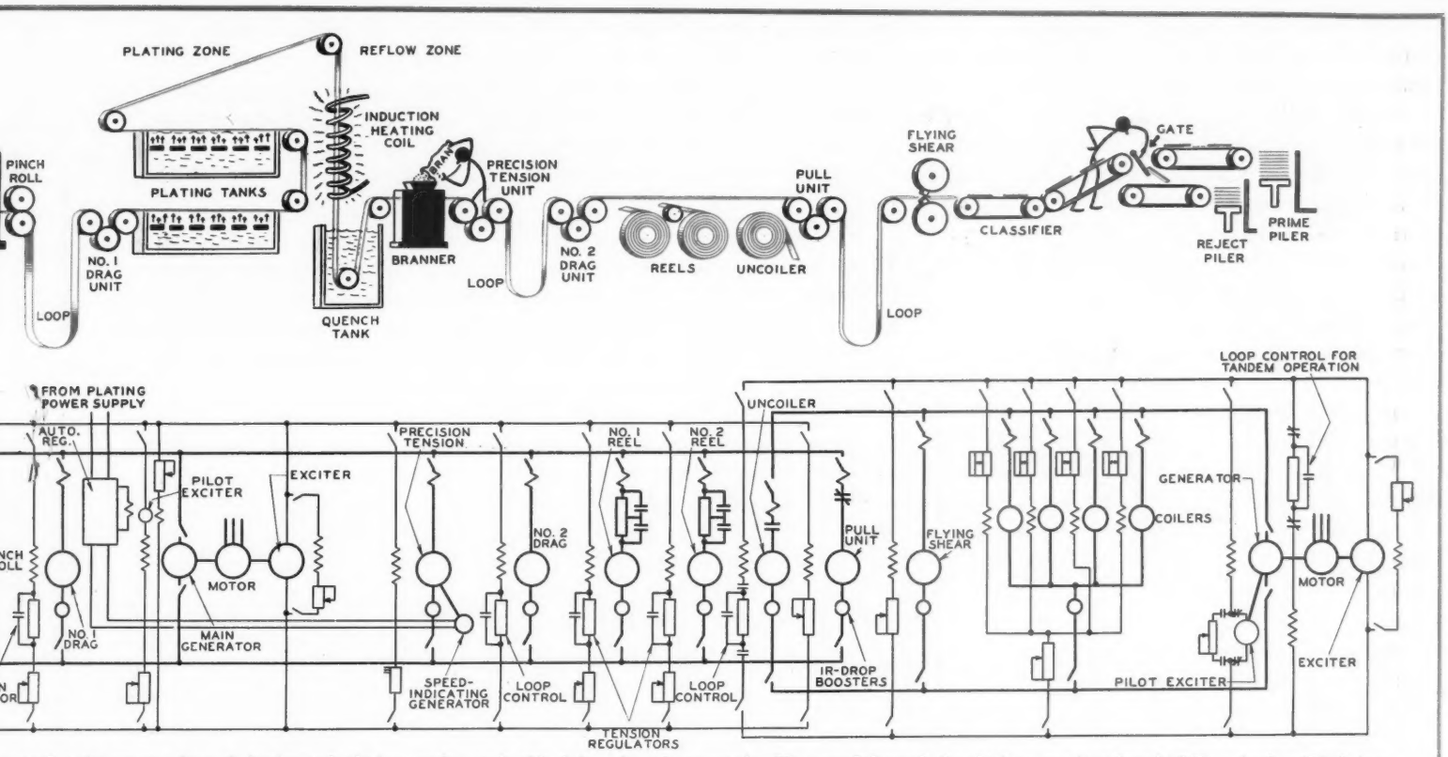
The thickness of the tin deposited or coating weight is a function of both time and speed. Hence, the plating power required is determined by the speed of the line at which a given coating weight is to be applied. Once these two factors have been decided the total plating power requirements can be determined, but this does not necessarily mean that heavier coatings can not be put on or that the line can not be run at a higher speed. Heavier coatings can be made at reduced speeds while lighter coatings can be deposited at higher speeds. It is essential only that the proper relationship between the total power and the speed be maintained for the desired coating weight.

The strip passes from the plating tank to the rinse to remove all plating solution that adhered to it. The strip then enters the master-pull unit. This roll is essentially the master unit of the entire line because the speeds of all the other drives are referred to it. This drive, therefore, fixes the speed at which the strip passes through the line. For this reason it always operates at full-field strength so that its speed depends entirely on the applied generator voltage.

From the pulling pinch roll the strip passes through the delivery looper into a tension device. This device operates as a drag generator to insure a tightly wound coil, so that the individual layers will not slip on each other when the coil is handled. Finally the strip is wound into a coil on the mandrel of the reel.

Another large problem remains for electrical control to solve. Like movie reels that must be changed without interrupting the picture, so must a fresh roll of strip be started

The author and a small part of the control board for a high-speed electrolytic tinning line. This board is over 200 feet long, possibly the longest industrial-process control switchboard ever built. The wiring-diagram blueprint for it measured 30 feet long.



e steel strip passes through horizontal plating tanks, each side being tinned separately. The speed through the plating zone is reduced while a fresh coil is being peed operation, up to about 1300 feet per minute. Shown also is the flying shear and sorting operation, not shown with the plating line on the preceding page.

through on the disappearing end of strip without altering the amount of tin being plated onto the steel in the plating tanks. When only a few turns remain on the uncoiler the operator accumulates as much strip in the entry looper as possible by speeding up the entry pinch roll slightly, if necessary. Then when the end of the coil approaches, the entry pinch roll is stopped, the end of the strip sheared off to square it, the end lapped on the new coil, which has been previously placed on the other uncoiler above it, and the two ends welded together. During this operation, which normally takes 30 to 40 seconds, the remainder of the line has been operating at normal speed, using the strip accumulated in the looper. On completing the weld, the entry pinch roll is started by a conventional magnetic controller and again operated from the variable-voltage bus. By a similar procedure the delivery end of the line can be stopped to change reels.

The principal advantages of a line of this type are its simplicity of control, the fact that motors of limited range of field control can be used, and relatively low strip speed requiring only a small amount of driving power. The control is simple, as the schematic diagram shows, because once the line is started the speed of the major part of the line remains constant even though at times either the entry or delivery ends are stopped briefly. Practically all the speed variation is obtained by control of the armature voltage. Therefore, it is possible to use motors provided with only a small amount of field control, which makes for a low-cost installation. Only the uncoilers and reels require any appreciable speed range. This is because the coil changes in diameter.

Variable-Speed, Vertical Line

The second basic type of line is a high-speed line with horizontal plating tanks and variable-speed plating. This line essentially consists of three distinct units in tandem. These are: first, the plating unit with uncoilers, pinch roll, No. 1 drag roll, and the plating unit; second, the reflow or fusion unit with the reflow zone, branner, and precision tension unit; and third, the shearing unit consisting of a pull unit, loop, flying shear, classifier, and pilers. This line has been designed for operation at 650 feet per minute, with provision for making changes to obtain speeds as high as 1300 feet per minute. Because a shearing line can not be operated faster than about 700 feet per minute without excessive buckling of the sheets, provision has been made for coiling the finished strip and then shearing it into sheets as a separate operation when the line is operated faster.

Tension is automatically maintained between the pinch roll and the uncoiler to prevent slack, the whipping action of which would probably break the strip. This same tension regulator also automatically compensates for the change in the diameter of the coil as strip is paid out. The loop is automatically controlled by photoelectric devices that speed up or slow down the entry end of the line as required.

Tension is automatically maintained in the plating unit by having the precision tension unit pull the strip through the tank against the drag produced by the No. 1 drag unit acting as a belt-driven generator. Tension must be accurately maintained to insure a good contact between the strip and the conducting rolls, through which the plating current enters the strip; also there must be no chance for the strip to touch the anodes, thereby short circuiting the plating cell and burning the strip.

From the plating tank the strip will pass through the reflow unit into the quench tank, from the quench tank

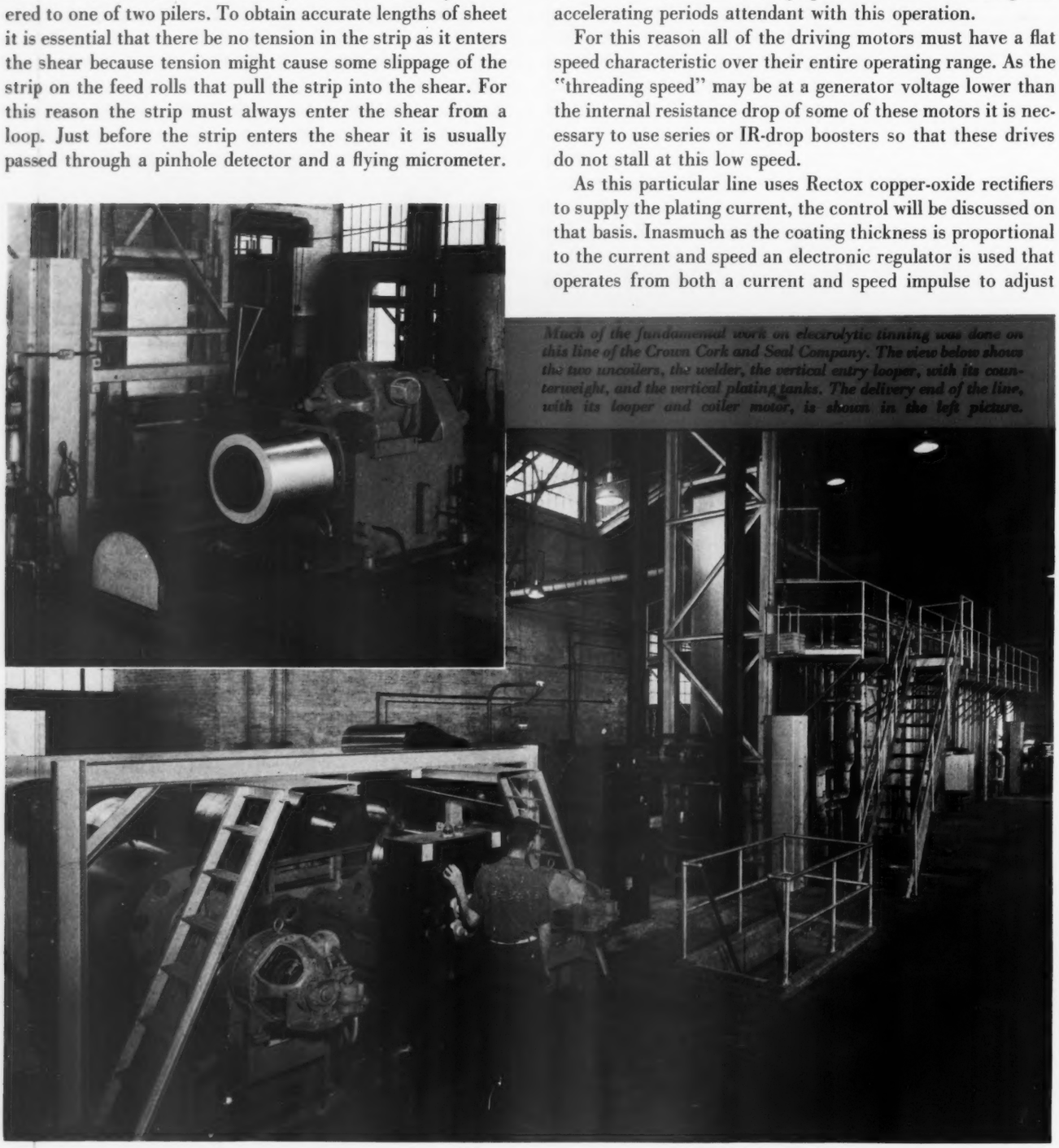
through the branner, and into the precision tension unit. In the reflow unit the electrolytically deposited tin is heated just to the temperature where it will flow and produce the mirror-like finish expected of tin plate. The strip is then quenched to harden and preserve this surface. Next, it is oiled and the excess oil is removed in the branning machine. It is important that the tension be accurately controlled through this sequence also.

The reeling operation for this line and the one previously discussed are the same. The strip passes from the No. 2 drag unit to the pull unit, through the pull unit into a loop, and from this loop into the flying shear. Thence it goes to the classifier where it is automatically sorted, and finally delivered to one of two pilers. To obtain accurate lengths of sheet it is essential that there be no tension in the strip as it enters the shear because tension might cause some slippage of the strip on the feed rolls that pull the strip into the shear. For this reason the strip must always enter the shear from a loop. Just before the strip enters the shear it is usually passed through a pinhole detector and a flying micrometer. These function to pick out the sheets with pinholes, and those too thick or too thin. A suitable memory device, either the pinhole detector or the flying micrometer, operates a gate, 10 to 15 feet beyond the shear in the classifier, to shunt the rejects into the off-gage piler.

It is not practical to have more than about 80 feet of strip accumulated in the entry loop. With the strip traveling 15 to 20 feet per second, this is only four or five seconds worth of strip. Because the welding operation requires approximately 30 seconds the line must be slowed down to weld on a new coil. These various drives must, therefore, operate in synchronism not only at the normal running speed, but also at a much lower "threading speed" and the retarding and accelerating periods attendant with this operation.

For this reason all of the driving motors must have a flat speed characteristic over their entire operating range. As the "threading speed" may be at a generator voltage lower than the internal resistance drop of some of these motors it is necessary to use series or IR-drop boosters so that these drives do not stall at this low speed.

As this particular line uses Rectox copper-oxide rectifiers to supply the plating current, the control will be discussed on that basis. Inasmuch as the coating thickness is proportional to the current and speed an electronic regulator is used that operates from both a current and speed impulse to adjust



Much of the fundamental work on electrolytic tinning was done on this line of the Crown Cork and Seal Company. The view below shows the two uncoilers, the welder, the vertical entry looper, with its counterweight, and the vertical plating tanks. The delivery end of the line, with its looper and coiler motor, is shown in the left picture.

automatically the speed of the entire line. This regulator is set for the desired coating weight; then, plating current is applied. This regulator adjusts the main generator voltage to operate the entire line at the speed to give this weight. To change the line speed it is necessary only to increase or decrease the total plating current accordingly.

To reflow the tin in the reflowing zone, a photoelectric regulator is used. This regulator scans the strip as it passes and regulates the heating medium accordingly. Such a regulator is possible, because tin, fortunately, is a solid at one temperature and just a few degrees hotter becomes molten so that the actual reflowing occurs in a narrow temperature zone. This regulator operates essentially as a position indicator and automatically compensates for any change in speed of the strip.

When the shearing unit is operating separately the photoelectric loop control operates in the field circuit of the uncoiler to maintain the loop, which is standard practice. However, when this unit is in tandem with the other two units this method of operation is obviously impossible. Instead, the photoelectric loop control operates in the field circuit of the main generator, used to operate the entire shearing unit. In this way the entire unit is speeded up or slowed down to maintain the proper loop.

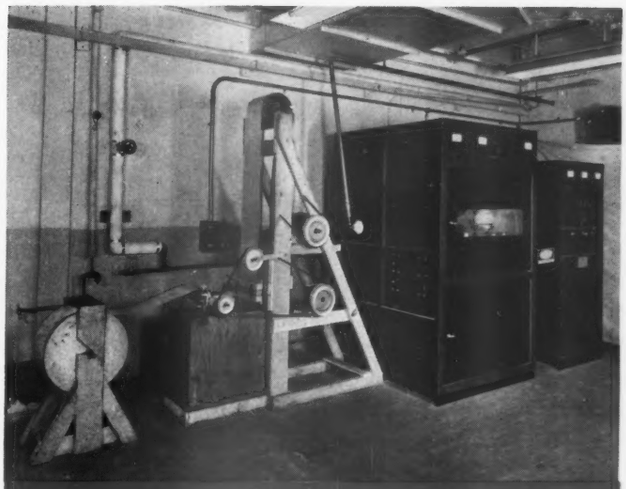
This second type of line requires the largest power input, which is natural because of its higher speed. The line uses about 25 d-c motors of from one to 125 hp, and approximately 75 a-c motors ranging from ½ to 60 hp. The plating unit requires approximately 60 000 amperes at 12 volts or 720 kw, direct current. A total of approximately 600 kw direct current is required from the generators to supply the variable-voltage power. This means, therefore, that the total power for this line at rated load and speed is about 2700 kw or 3600 hp.

Reflowing or Refinishing

The tin plate produced on one of these electrolytic lines has a gray matte surface. The smooth, polished surface to which we are accustomed can be obtained by heating the surface of the tin so that it flows slightly and then quickly cooling it. This reflowing is necessary not only to improve the appearance, but to reduce the porosity of the coating and improve its corrosion resistance. Several methods have been proposed for this reflowing operation. The most important of these are: 1—passing the tinned strip through a hot-oil bath, 2—passing the strip through a radiant tube or some other type of furnace, 3—using the electrical resistivity of the strip itself to heat it conductively, and 4—to pass it through a high-frequency inductor heating coil.

The hot-oil bath can be used successfully on low-speed lines. Because the differential between the melting point of tin (450 degrees F) and the temperature at which the oil can safely be heated is low the speed is limited. Further, because the temperature of this reservoir of heat cannot be quickly altered, the strip must be passed through the bath at constant speed.

The furnace method also is satisfactory for low-speed work, but becomes quite bulky as the speed of the strip is increased. The furnace must be nearly one half foot long for each foot per minute that the strip travels; a practical



Much of the early experimentation of reflowing of electrolytically deposited tin by high-frequency induction was performed on this laboratory equipment. The tinned sheet is seen passing vertically through the inductor coil; power is generated at the right.

limit of 200 feet per minute is set for the radiant-furnace method. Here again, the heat can neither be generated nor dissipated at a high rate, which restricts its use to a constant-speed operation. Both the hot-oil and the furnace methods do not lend themselves readily to incorporation in the electrolytic-tinning line itself, but make reflowing a separate operation. This, of course, entails additional handling of the strip during processing.

Melting the tin by the heating effect of current flowing through the tin plate itself does not have the speed limitations of the hot-oil or furnace method. Neither does it restrict the process to a constant speed inasmuch as the current can be readily controlled as the speed is changed. With this method, however, there is the problem of getting the power into the strip at high speeds without arcing and burning at the contact rolls where the power is introduced into the strip. Because the strip with the coating heated is in actual contact with the current-collecting rolls, there is a possibility of marring the tin surface. By this method it is necessary to heat a section of the strip while at the same time attempting to quench it.

By the induction method the tinned surface is brought to the melting point of tin by the same methods now extensively employed by industry in electromagnetic heating except that the frequency and power involved are much greater. In fact, the equipment is a broadcasting set of enormous power. Based on a strip speed of 1000 feet per minute an oscillator of about 1200-kw output is required for most commercial strip. The largest commercial radio broadcasting stations are limited to a maximum of 50 kw. Thus just one of these induction-heating units has a radio-frequency output of 24 such broadcasting stations. This equipment requires approximately 2300 kw of power, and covers a floor space of approximately 650 square feet.

In the induction system there is no physical contact between the strip and any stationary or rotating member. Thus, there can be no marking of the strip either by electrical or mechanical action. The space required for heating is in the order of 10 to 12 feet at a speed of 1000 feet per minute. No

heating is done at the time that the strip is being quenched as the strip does not enter the quench until after it has left the heating zone.

Inasmuch as reflowing of tin is a relatively new operation, practical experience may indicate the wisdom of using some combination of these reflowing methods. Such a combination might be both electric conduction and induction, in which the tin is preheated by current carried through the strip and the final heating to the reflowing temperature is accomplished by induced current.

The complete process of tinning steel can now be performed in one line instead of several separate operations, each requiring additional handling of the steel. The coating applied has been reduced to approximately one-third, by weight, of its former value. This development, is therefore, one of the major advances being made in the steel industry.

Balancing the Tin Budget

(Continued from p. 116)

tin is first dissolved with sodium hydroxide. One process then recovers the tin from the resulting sodium stannate solution by electrolysis, and another reduces the solution by flue gas or carbon dioxide to tin oxide and sodium carbonate. The oxide is then reduced in reverberatory furnaces.

Despite all these economies the supply of tin is still critically short. However, sufficient reductions in the use of tin have already been made to deny the Axis any hope of victory by way of tin. The cost in inconvenience, engineering time, and actual dollars has been high, but much of permanent value has been obtained. Many new processes, many new materials are being found superior to the old ones. We are learning the hard way, but we are learning.

Power on the Road—Electrically

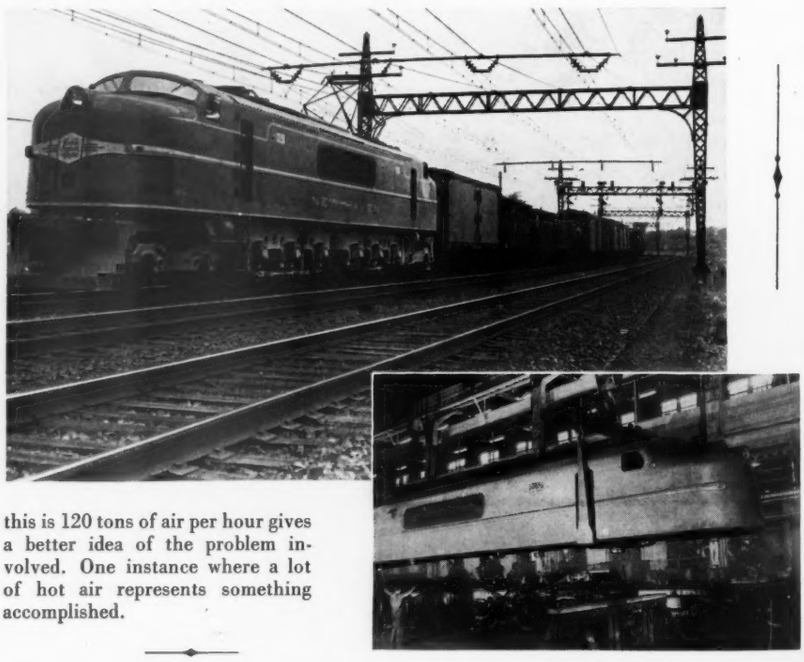
Electric locomotives hold a fascination of their own, whether they be toys or the new 250-ton freight locomotives recently put in service on the New Haven Railroad.

Conditions of operation called for a locomotive with seemingly impossible contradictions. It had to be heavy enough and big enough to haul a 125-car (5000-ton) train over the New Haven saw-tooth profile trackage on rigid schedule and yet keep within severe weight and size limitations imposed by tunnels, bridges, etc.

The answer was a 500 000-pound locomotive with 360 000 pounds on the 57-inch drivers. Using a 4-6+6-4 wheel arrangement, having six twin motors of 810 hp developing a maximum of 9000-hp tractive effort, the locomotive replaces three of the old type formerly used and pulls the same load at an increase in speed of 41 per cent.

The articulation between the two sets of six drive wheels reduces the rigid wheel base to 13 feet 8 inches, allowing the negotiation of the sharpest curves, this in spite of an overall length of 80 feet.

The engineer is surrounded on three sides by 40 000 pounds of transformers, relays, and assorted controls. Careful packaging was required to meet space requirements while still retaining adequate capacity to operate the six twin motors at an aggregate 4860 hp at 65 mph continuous rating. The safety of the engineer was assured by using Inerteen-filled transformers, giving the advantage of liquid filled without the fire hazards attendant upon the use of other coolants. To reduce currents in the control circuits, each pair of twin motors is connected in series. Power transforming capacity was raised by use of forced ventilation at 50 000 cubic feet a minute. That



this is 120 tons of air per hour gives a better idea of the problem involved. One instance where a lot of hot air represents something accomplished.

Primarily designed as freight locomotives, they are readily converted to passenger service by installing train-heating equipment in a space provided. As designed, they can be used for hauling a 20-car train of 85-ton Pullmans between New York and New Haven on any existing schedules. A possible 66 steps in the engineer's control makes for smooth operation of any size train. Sleeping and soup consumption are thereby facilitated.

Track profile plus space and weight restrictions necessitate use of momentum in negotiating grades. A surplus of momentum to flatten the next hill would be available with 5000 tons at the maximum 65 mph. In practice, the power of these locomotives, unequaled by any other type of locomotives, such as steam or Diesel-powered, is such that speed up the succeeding grade can be maintained. While the nominal continuous rating is 4860 hp, for short times they can develop 90 000 pounds traction effort at 38 mph or 9100 hp. This power-weight-size achievement was largely due to the steady decline in the weight-per-horsepower, which is now nearly two-thirds less than it was some fifteen years ago. Having your cake and eating it is always a good trick, and in this instance it was done. Engineering plus.

The locomotive crew must be Argus-eyed. All that they must watch, in addition to block signals and other outside railroading controls, are the following: cab signals, air brake gauges, current in each motor, locomotive speed and a group of illuminated panels which show main field-low speed, interpole field-high speed, drivers slipping, blower stopped, a-c primary relay tripped, and preventive coil relay tripped.

Small Damper Keeps Fan System from Oscillating

That there is a time and place for everything certainly holds true for oscillations. However, there is definitely no time or place for torsional oscillations in a vital ventilating-fan system such as is used in the Pennsylvania Turnpike tunnels. This hydraulic damping device neatly eliminates them.

S. F. HENDERSON
Motor Engineer, Westinghouse Elec. & Mfg. Company

Pennsylvania Turnpike tunnel ventilating fan.

THE proper functioning of a system of machines is dependent, not only upon the performance of the individual components, but also upon the correlated performance of the several components as a unit. A good example of such an assembly is the fan system ventilating two Pennsylvania Turnpike tunnels. Each of the individual parts—the two-speed driving motors, reduction gears, and fans—has performed correctly in other installations. Yet these parts in combination developed torsional oscillations during a portion of the accelerating period, causing shaft oscillations and objectionable noise.

To obtain three running speeds, each fan was driven, through a reduction gear, by two motors. One rated at 40 hp drives the fan at 1175 rpm and the other, of 5.5/0.9 hp, provides speeds of 580 and 290 rpm. During acceleration by the larger motor, oscillations developed at approximately 750 rpm, increased in amplitude and reached a maximum at 900 rpm, and then decreased and vanished at about 1000 rpm. At speeds below 750 rpm and above 1000, operation was normal, the drive being quiet and free from oscillations upon attaining rated operating speed. A similar behavior was observed when the fan was driven by the smaller motor, although some installations were free from oscillations at slow speeds.

Analytical studies and torsiograph tests by research engineers disclosed that these oscillations resulted from insufficient damping. Because of the large inertia of the fan—about ninety times that of the driving motor—the accelerating period was long, about one minute. With a given tendency to oscillate, the amplitude of the oscillation was allowed opportunity to develop as the natural period of the machine was reached, because of the relatively long period of acceleration.

The damper developed to prevent the oscillations consists principally of two parts. The outer case is keyed to the motor shaft, which extends through it. The inner part, a mass free to oscillate, is a disc from which two segments are cut away to form oil chambers. Four springs tune the damper to approximately the natural frequency of the whole system. When torsional oscillations develop in the shaft, the oil is forced from one chamber to the other through narrow orifices in the disc. This absorbs enough energy to prevent shaft oscillation from increasing in magnitude.

The damper, although small, shown in Fig. 1 to be about the size of a coupling, is well able to smooth out the torsional oscillations of the blower installation. The correction obtained is strikingly demonstrated by the curves in Fig. 2, the final torsiograph showing no tendency toward a natural period of oscillation by the shaft such as was shown in the first torsiograph before the damper was installed.

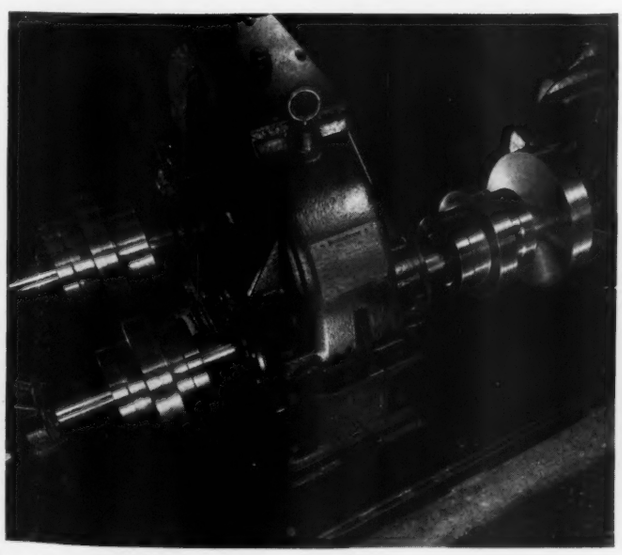


Fig. 1—The disc-like device placed between motor and shaft coupling is the damper that inhibits oscillation during acceleration.

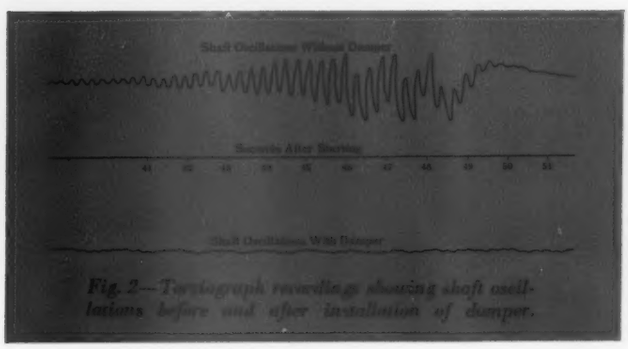


Fig. 2—Torsiograph recordings showing shaft oscillations before and after installation of damper.

Stories of Research

Enamel Scrape-Testing Device

WITH MEN, machines, and materials alike it narrows down to this; can you depend on them? The final test is the test of use. Many electrical insulators apparently have excellent characteristics until they are given the test of service. Enamel wire, for example, in the ordinary processes of industrial application is given a torture test such that only the toughest survives. When used in some types of motors, it is machine-wound on coils which are in turn forced into partially closed slots. In this operation several strands of wire at a time are forced through small openings, the rough edges of which offer excellent possibilities for scraping or abrading the wire. Can the insulation take it? Some reliable scrape test is necessary to check this.

There have been various kinds of scrape-testing devices for many years. In general, an insulation scrape tester is comprised of a flat plate over which the wire is pulled. Resting on the wire is a scraping "head" upon which weights can be placed to increase the pressure on the wire insulation to be tested. On the bottom of the head, at right angles to the length of wire under test is secured a length of steel wire which acts as the knife edge in scraping the insulation. As the enameled wire is pulled by hand through the machine the steel-wire knife edge scrapes the insulation with a force proportional to the number of weights imposed upon the head.

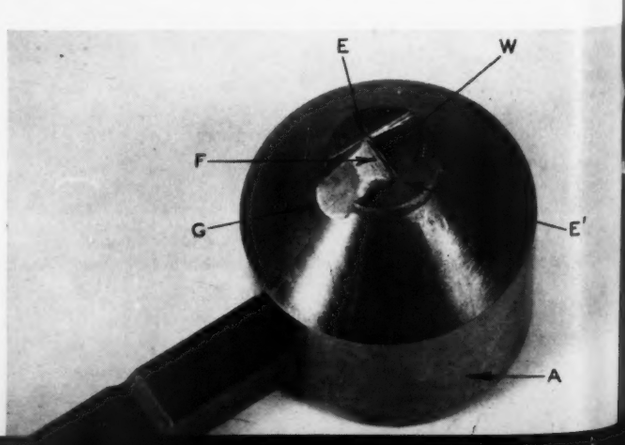
There are four inherently undesirable features that in the ordinary comparator introduce unresolved variables in the test result. Two faults are of a mechanical nature, and two are a matter of procedure, which can be corrected. One cause of irregular results is the manner in which the weights are superimposed upon the scraper head. The cylindrical weights slide in a close fitting hole which keeps them in alignment. Any binding on the side walls during a test does not allow the full weight to be impinged upon the scraper, and a true reading of the results is impossible. Also in the head the wire that serves as a knife edge is supported firmly only at the ends which are over two inches apart. The wire is thus free to move laterally when a test wire is pulled over it. Any such movement or a stretching of the steel wire will give an angle of scrape less than 90° with no uniformity of readings. When the wire is pulled through by hand only the most experienced operator can closely duplicate the rate of pull from one test to the next. Further, the angle of pull varies with each test as the wire is not guided through the machine in one plane, but is dependent upon the movement of the operator's arm for the horizontal motion. To end these "human element" factors and further enhance the value of the test by scraping four sides of the same wire during each test, this wire scrape-testing machine was designed.

To avoid these weaknesses of design and technique, Charles B. Leape, of the Westinghouse Research Laboratory at East Pittsburgh, devised an improved scrape-test machine. The foundation of the machine is comparable to a small lathe bed. A movable head or chuck moved laterally by a fractional horsepower electrical motor pulls the wire in a plane strictly parallel to the test-piece base at the constant rate of two inches per second. This is accurately controlled by a properly geared synchronous motor. The scraping head itself is mounted on a pivoted arm so that when the scraping wire is on the test piece, the center line of the applied weights is perpendicular to the test piece, and there is no variation in the comparative readings from unaligned weighting. The scraping wire, made of carbonized tungsten, because it has a Brinell hardness number over twice that of music wire, and only occasional replacements due to wear are necessary, is held rigid throughout its length by soldering in a groove. As the wire is firmly fixed and does not give or spring to any extent, the angle of scrape remains constant. The outer edges of the face containing the scraping wire are a few thousandths higher than the wire itself which prevents the wire from carrying the weight of the loaded head when the test wire is removed and being flattened against the base plate.

The chuck is provided with a spring that rotates it in a clockwise direction. The illustration below shows the arrangement of welded bars that hold the chuck in a certain position for a specified distance and then permit it to rotate 90°, turning the wire by that amount and thus scraping it on a new face. Four such movements are provided. A reversing switch is provided for the chuck drive. A low a-c voltage is applied across the insulation, so that insulation failure causes a sensitive neon lamp to light. A low-voltage, low-current indicator is necessary to avoid introducing an electrical factor that might aid in the insulation breakdown.

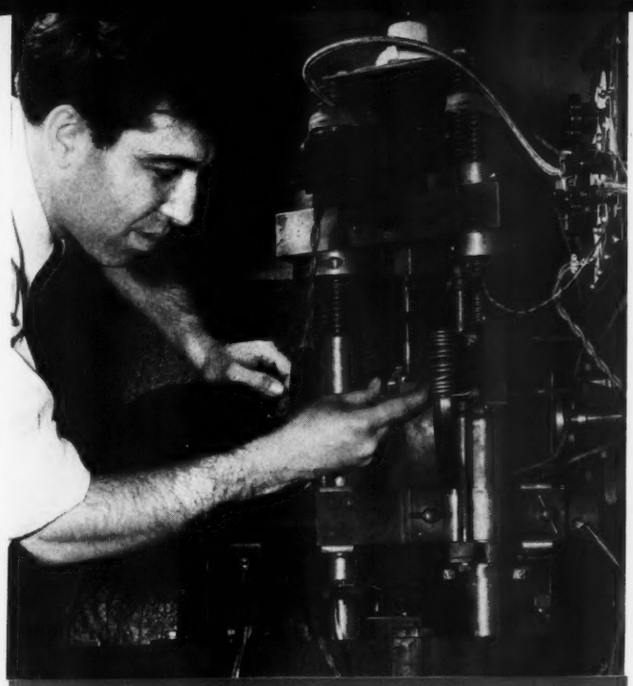
The scope of this machine is necessarily limited to the comparative testing of scrape resistance of enameled wire insulation. However, in that it tests four separate sections of the wire 90° apart, it is also a measure of the uniformity of the enamel coating. Its principal merit rests on its ability to make uniform scrape tests that can be closely compared. One value of the scrape tester is that it does not confuse scrape and abrasion and is equally at home in testing the old, softer enamels as well as the new, hard, synthetic polymerized resins. Aside from the routine testing, this scrape-test machining is well adapted for testing newly developed insulations where slight differences are important in determining the direction and progress of experimentation. It furnishes consistently accurate data not available with the old type of scrape tester.

Mr. Leape demonstrating the scrape tester.



Detailed photograph of the head of the scrape-testing device.

This view shows how the hardened steel wire *W* is set in the groove *F* is soldered. The head metal at *G* is cut away to allow for easy removal scrapings. The surfaces at *E* and *E′* are higher than the wire *W* so that damage ensues if the head is permitted to drop on the bottom plate of machine. The weight of the body of the head *A* is exactly set and additio loads are achieved by stacking weights on top of the head as is shown the general view of the machine.



The specially designed testing machine for determining tensile strength at high speeds. Mr. Manjoine is adjusting the anvil on the test piece which is struck by hammers on the large wheel.

Speed Laws for Metals

THE CURRENT universal cry is for speed and more speed. However, as we have found in the automotive industry, speed involves hazards. Speed should be limited by the degree to which it can be controlled. High-speed cars could not be evolved until the advent of four-wheel brakes. High-speed handling and forming of metals at varying temperatures with safety from an engineering standpoint must wait upon the formulation of laws controlling this speed: applying the brakes of scientific findings on engineering development of rolling mills and other devices. Dr. A. Nadai and Mr. Michael J. Manjoine have been delving deeply into these speed laws for metals with interesting results.

The testing of metals is largely a matter of measuring the forces necessary to accomplish the various stages of deformation, including failure. These generally are most readily measured by tensile tests in which the specimens are literally pulled apart. The manner of deformation does not affect the findings as long as the conditions under which the test is made are kept constant for purposes of comparison. Normal commercial testing specifies the size and shape of the test piece, the test to be conducted at usual atmospheric temperature and a strain velocity considered normal at about one-tenth of an inch per inch per minute. In order to test the characteristics of metals deformed at high speeds, Dr. Nadai and Mr. Manjoine developed equipment for the testing of metallic specimens in tension at a speed of some 80 miles per hour or roughly 800 000 times as fast as the normal strain velocity.

This required not only a means of developing a fast-moving source of force capable of delivering a blow equivalent to that of a 1000-pound sledge but also timing the blow and recording the elongative stresses and strains developed through to complete failure. In their high-speed tensile testing machine, a motor-driven flywheel revolves with a peripheral velocity of 100 feet per second. The test specimen is suspended from a "force-measuring bar." A collar or "anvil" is fastened to the lower end of the specimen. When the flywheel has attained the desired speed, a trigger releases two hammers on the outer edges which strike the collar or "anvil" and pull the test piece in two parts in approximately five ten-thousandths of a second. To record the physical stresses and strains developed by the machine at this speed, an ingenious combination of light source, photoelectric tube, and cathode-ray oscillograph is used. The stress is measured by the deflection of the force-measuring bar, which opens a two-thousandth inch slit in a shutter through which a beam of light falls on a photoelectric cell. The greater the stress the more light is permitted to pass through the shutter and the greater the amount of photoelectric current; this current is amplified and results in a vertical deflection of the beam in the cathode-ray oscillograph. The strain or elongation is measured in a comparable manner except that the greater the elongation, the more a light beam is cut off in a shutter and a corresponding photoelectric current results in a horizontal deflection of the beam in the cathode-ray oscillograph. The resultant movement of the beam presents a stress-strain diagram of the test piece and this is recorded by means of high-speed photographic equipment.

Tests showed that a steel specimen, at about 70° Fahrenheit had some 30 per cent greater tensile strength at high testing speeds than at normal testing speeds. The same holds true for non-ferrous metals except that the percentage increase in strength is greater.

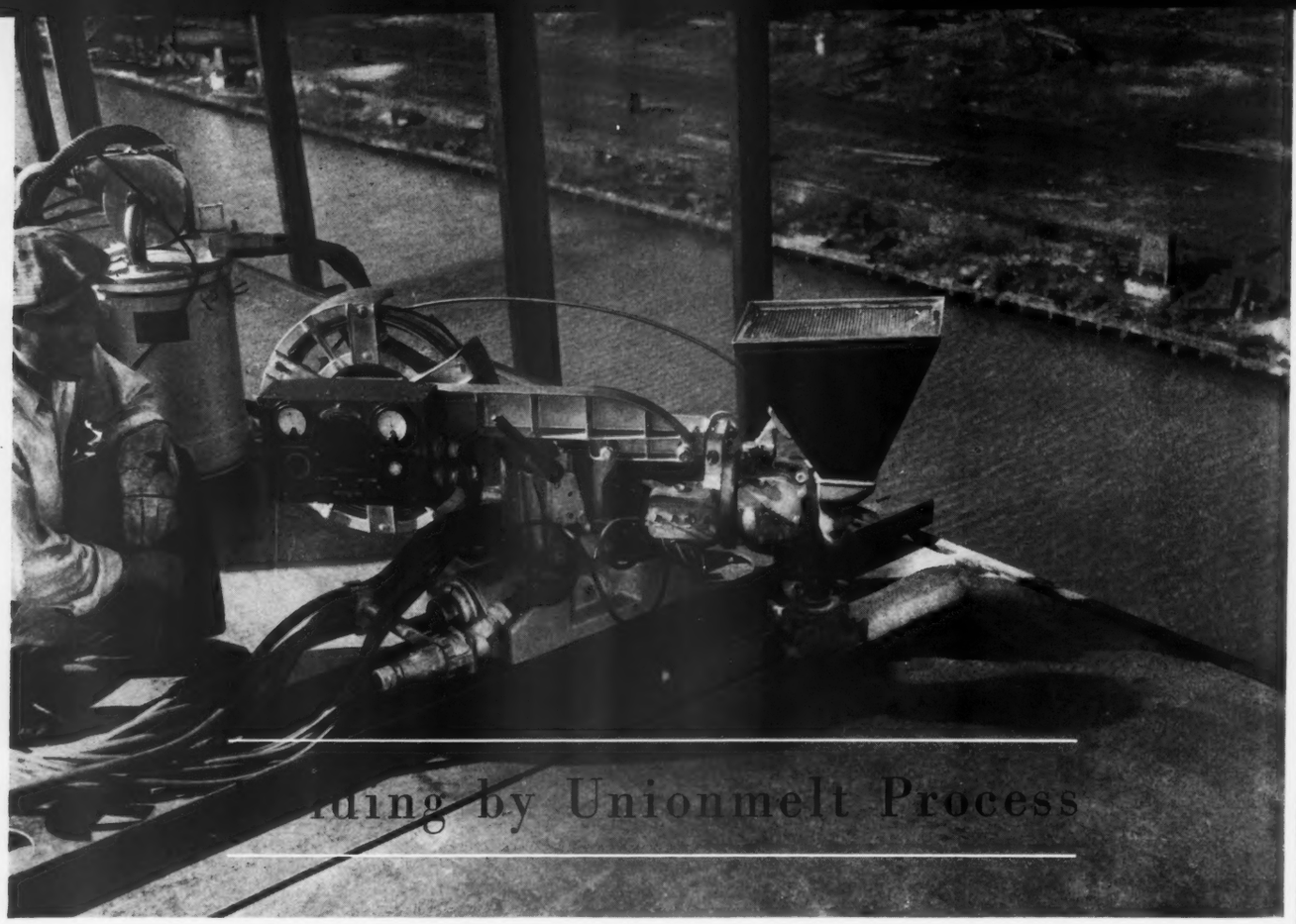
In addition to tests at normal atmospheric temperatures, specimens were subjected to high-speed tensile tests at high temperatures also. This was achieved by means of a small electric furnace. While steel is obviously more readily deformed at high temperatures, the tests showed that at 1832° Fahrenheit the specimen offered some five times as much resistance to deformation at high speed than it did at normal speed. Tests were conducted as high as 2212° Fahrenheit with comparable results.

Although these tests were all in tension, the same results apply in compression, other factors being comparable. From the data being accumulated, practical help to steel mill men should ensue for determining the maximum speed and the proper temperature at which their present rolling-mill equipment can operate most efficiently. Other applications involved are not confined to the ferrous group of metals. The extruding of aluminum and wire drawing in various metals all have the same fundamental physical principles in common. The results should also be beneficial in the designing of new, higher speed metal-forming machinery in addition to establishing a technique for the determining of the "speed laws" for other metals.

Design for Unscrambling

TO THE uninitiated, all Orientals look alike. An intimate knowledge of their characteristics is necessary to differentiate individuals. A similar problem presented itself to Mr. C. S. Williams of the Research Laboratories in attempting to sort a mixture of identical-appearing small metal parts, some of which had been heat-treated and some of which had not been treated. The required intimate knowledge of the metal parts was readily obtained by a simple system of balanced magnetic fields tied in with an oscilloscope for ready visual determination of the results. In the above problem, the heat-treated metal parts were susceptible to a greater degree of magnetism and the magnetic field became relatively larger than was the case with the untreated parts and the segregation was easily completed. This method of selection is adaptable to the discrimination between all kinds of identical-appearing iron and steel parts, providing that there is present a characteristic that will have an individual effect on a magnetic field.

Mr. Williams, with the magnetic discriminator, separates heat-treated from identical-appearing parts not heat treated.



...ding by Unionmelt Process

In times of national emergency from 1776 to 1941, men have not changed and need of shipping has not changed. The manner of supplying that need has changed. During the fighting eras of Jones, Decatur, Farragut, knowing hands wielded mauls to supply stout wooden vessels. For Dewey and Sims, the clangor of riveters echoed endlessly to meet the naval demands. Now, the challenge of a whole world's need for ships to carry food, raiment, men and arms, is met with welding. This quiet unostentatious mass-production technique is evolving ships incredibly fast. Not only for ships, but also for tanks, heavy ordnance and other tools of war and of peace, wherever heavy material must be welded quickly, the Unionmelt process will be found.

IN THESE days, time is a plus or minus factor in national safety, depending upon its use. Unionmelt is definitely on the plus side in its use of time. The average manual weld-metal deposition is about six pounds per hour whereas, using a current of 3250 amperes, Unionmelt deposition is about 125 pounds per hour. Although a comparative newcomer in the rapidly expanding welding field, this process in the past several years has been establishing peaks in the standards of practice in this industrial art. Within its particular scope, producing clean, fast, one-pass welding in large volume on materials of all commercially available thicknesses using a minimum of weld metal and requiring a minimum of operator skill, Unionmelt has been supreme. Especially in repetitive heavy shipyard welding has this process demonstrated its unspectacular efficiency in "getting thar fustest with the mostest" welds.

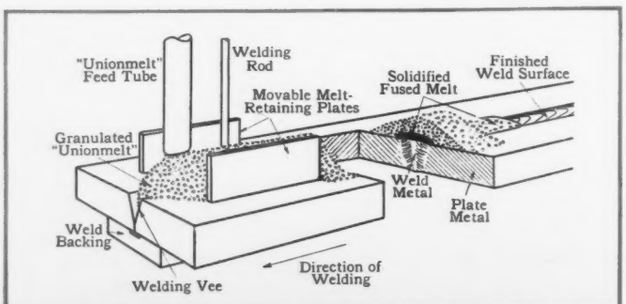


Fig. 1—Diagrammatic sketch showing manner of butting plates to be welded, backing up weld, supplying granulated Unionmelt to cover welding operation, and controlling granules during the welding process. Cutaway view shows character of weld and manner of protection by fused Unionmelt.

The Unionmelt process differs materially from the familiar arc- and resistance-welding procedures. Although weld metal is transferred from a welding rod to the parent metal as in arc welding, there is no visible arc. Whereas in ordinary resistance welding heat is developed by current flowing through the members to be joined, in Unionmelt the electrical resistance of the parent metal, the weld rod, and a third substance, Unionmelt, from which the process gets its name, fuses the weld rod and parent metal.

The crux of this process lies in its use of the glass-like crystalline compound as a blanket for the welding operation. These granules are a non-conductor of electricity when cold

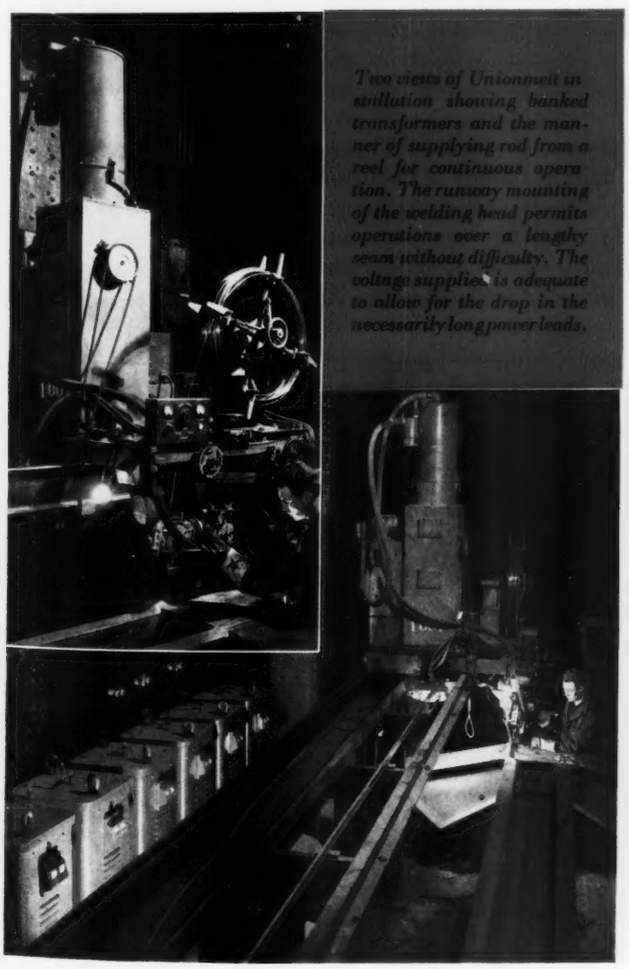
This article based on data supplied by Mr. F. G. Outcalt, Unionmelt Division, Linde Air Products Company.

but are a high resistance conductor when molten. The welding action is usually started with a steel wool "starting fuse." At the start of the weld, a pad of steel wool is placed between the rod and the seam to be welded and the whole arrangement is covered with the compound. High currents melt the steel wool and a portion of the Unionmelt crystals. Upon being melted, this high resistance blanket aids in the generation of sufficient heat, through the flowing heavy currents, to melt the rod and the parent metal on both sides of the seam, forming an unusually fluid weld "puddle." The excellence of this type of weld is partly dependent upon the degree of fluidity of the weld point. Through the turbulence of the molten parent and rod metal, there is a complete admixture of the two in the proportions of about 1.7 to 1, representing a distinct economy in welding rod material.

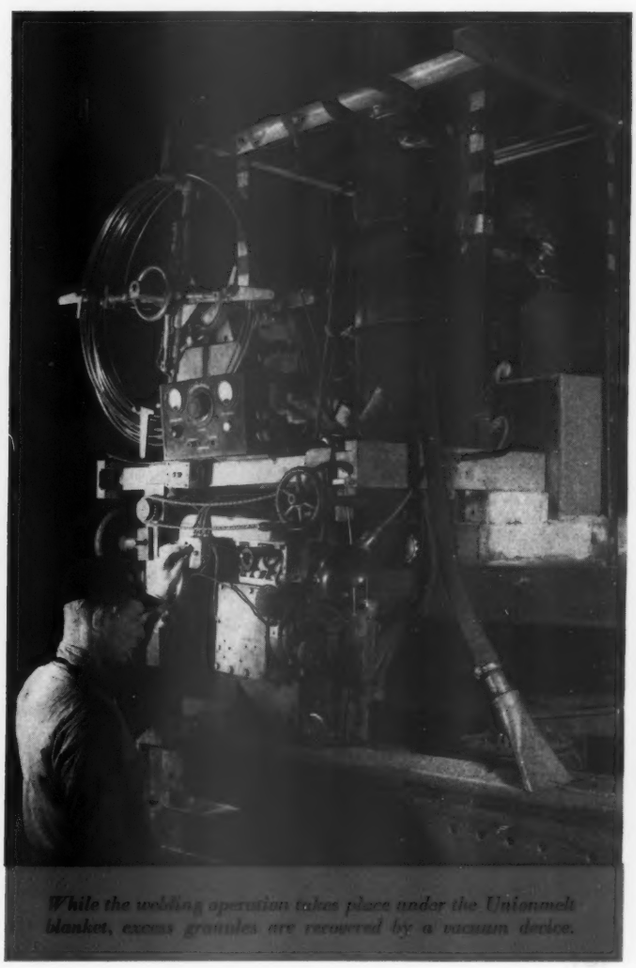
After the weld is started, its continuance is practically automatic. This is achieved through the use of a "welding head." This head performs several important functions. During the weld, it moves continually with relation to the seam, either through moving along the seam or having the seam pass beneath while the head remains stationary. During this relative motion it spreads a mound of Unionmelt over the seam so that the entire length of the weld is carried on beneath the coating. It also feeds the proper amount of welding rod to the weld, this often being drawn from a reel and permitting continuous operation. Finally the welding current, supplied by a transformer, is provided by the head in correct amounts at the weld. While under the nominal control of an operator, the whole action, once started, is practically automatic and removes to a large extent the human element from the character of the weld.

The manner of moving the head across the work or moving the work under the stationary head depends on the individual job. Small I-beam members are used for tracks on small heads; large carriages, trackways, and gantry cranes are other devices used. Often the work is passed under the welding head on rolls.

One of the salient characteristics of this process is that the point of weld is quite fluid and not merely plastic. The fluidity of the weld "puddle" makes for excellence of the union of the seam edges, but it also limits the application of the scheme. This same fluidity demands that all welding must be on a horizontal plane, or nearly so, and must be "downhand." Furthermore, in rapid, one-pass welding of materials, up to two and one-half inches thick, the parent metal becomes fluid throughout its thickness, necessitating a backing up of the weld to keep the "puddle" from falling through. Often a copper bar is used to back up a weld, or a copper shoe that travels with the head; under certain conditions a piece of steel is used which becomes part of the weld. Where this is undesirable, a manual weld is made on the under side of the seam. Sometimes a trough of the Unionmelt com-



Two views of Unionmelt installation showing banked transformers and the manner of supplying rod from a reel for continuous operation. The runway mounting of the welding head permits operations over a lengthy seam without difficulty. The voltage supplied is adequate to allow for the drop in the necessarily long power leads.

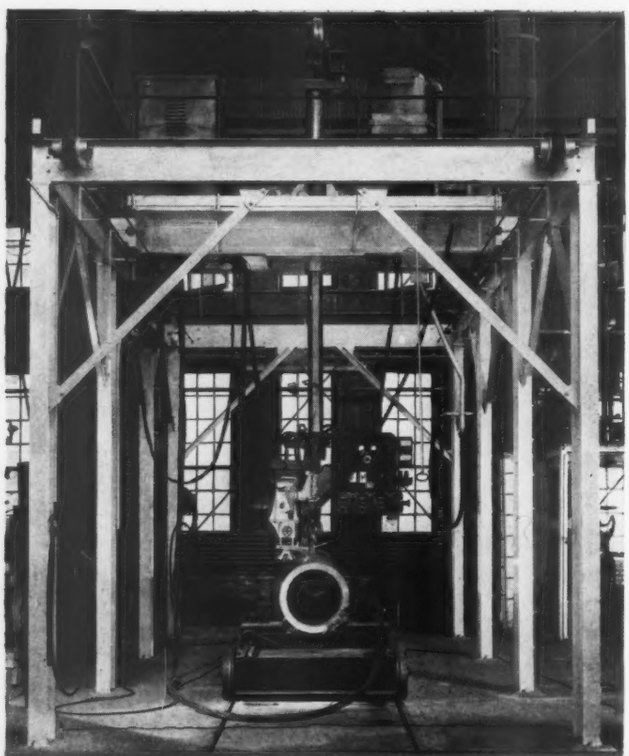


While the welding operation takes place under the Unionmelt blanket, excess granules are recovered by a vacuum device.

pound is held up against the under side of the seam, to support the fluid metal.

One of the principal problems in all welding has been the protection of the weld during its formation from rapid oxidation and from the inclusion of other gases. Coated electrodes were developed for arc welding and gave practical relief through developing a cloud of gas about the arc which shielded the molten metals from the atmosphere. In the Unionmelt process this same blanketing is accomplished by the molten Unionmelt and by the unfused particles, only much more completely. This material not only excludes the air completely, but no gas is generated when it is heated.

Because of the elimination of splatter at the weld point and the inherent characteristics of the molten Unionmelt,



In this adaptation of the Unionmelt welding head specifically for welding heavy pipe, the head is suspended from an overhead crane, the transformers also being mounted on the crane. Here the work is rotated while the head remains stationary.

greater current densities are permissible than with arc welding, which, even with improved rods, does not exceed 9000 amperes per square inch. Current densities from 14 000 to 30 000 amperes per square inch are commonly used in Unionmelt. The higher current densities give a more concentrated heat which is responsible for the increased rate of deposition, the complete fusion of the entire thickness of the parent metal in a minimum time and permits rapid single-pass operation.

This comparative rapidity of welding reduces the amount of induced heat in surrounding parent metal so that shrinkage and its attendant distortion is practically eliminated. Because the system precludes excessive stresses being sealed into the weld, peening or other conditioning steps are eliminated. Through the lack of locked-in stresses, and because of the depth and fluidity of the weld, the tensile, bend, impact, and fatigue strengths of the weld approximate those of the parent metal and compare favorably with them.

This system requires a load voltage of 20 to 55 volts, either alternating current or direct current. Alternating current is generally used for several reasons: economy, availability of power, ease of handling, and the facility with which the system is operated from transformers. Westinghouse welding transformer units for the Unionmelt process are rated from 500 to 2000 amperes. The 1000-ampere rating is practically the standard unit and two or more units are operated in parallel when loads exceed the current capacity of a single unit. The units are designed for high efficiency, with natural cooling. Stepless current adjustment is obtained by motor-driven, movable-core control, this allowing the welder to be set for a predetermined current before starting to weld and also permitting current adjustment while welding. Built-in remote control enables the operator to start and stop and make welding current adjustments by means of push buttons at the welding head.

In heavy welding operations, considerable time and machining equipment are normally used to prepare the edges for welding. With this process, however, the edge preparation is eliminated or minimized. There is no necessity of machining the edges to "U" or "J" joints in any case. On filets or T-butt joints, there is no necessity for making a vee preparation on any material up to one inch thick. Where a vee preparation is necessary, it can be much smaller than in other processes.

With the Unionmelt process one-pass butt welds on one-inch plate can be made at the rate of 10 to 12 inches per minute. One-pass butt welds on two-inch steel plates can be made at the rate of five to six inches per minute. Steel plates up to two and one-half inches thick can be welded in one-pass and five-inch steel plates can be welded using one-pass on each side. To these remarkable figures add the fact that in weld metal deposition Unionmelt out-performs manual operations more than 20 to one, and its superiority in its particular field is appreciated.

To be utilized to greatest advantage, the welds must be of sufficient size, length, and numerical volume to warrant setting up automatic or semi-automatic jigs for rapid handling. The process is extensively used in the fabrication of ships, boiler drums, and other pressure vessels, steel railroad bodies, and other heavy work of this nature. Many applications for it have been developed in war material production. This process finds ideal application in the pre-fabrication of large units of ship construction that can be lifted bodily onto the ways and there welded to other units. Unique and time-and-labor-saving devices such as jigs, traveling platforms, and gantry crane suspensions have been evolved for the efficient mounting of the Unionmelt heads or motivating the material itself. Under these conditions the process is without a peer. There are numerous industrial applications, such as continuous welding of large pipes, and Unionmelt welding is generally thought of as confined to mechanized, repetitive operations of considerable bulk. Its limitations however, are dictated by purely physical considerations of the work to be done.

Laying Stress on Strains

Mr. B. F. Langer securing cover plate on submersible gage.

Man has supplemented his five senses by inventing devices that detect and harness forces beyond his perceptions. The radio, black-light devices, the microscope are famous ones, but among them should be included the strain gage. It does a great deal with very little. With only the imperceptible stretch of a steel member as it shoulders a load, the gage gives an accurate account of the strain. Such ability seems reserved for a laboratory device, but the strain gage has all the ruggedness and reliability expected of a workaday tool. The gage has many practical uses.

B. F. LANGER
Research Engineer, Westinghouse Electric and Manufacturing Co.

THE WHIP and thud of an oil-well sucker rod half a mile deep in the ground; the thrust of the ponderous locomotive drive rod; the violent twist of the shaft in a 40 000-hp wind-tunnel motor; the powerful whirl of a ship-propeller shaft; these are forces, not only to conjure with, but to measure and to analyze. How? With a magnetic strain gage, no bigger than your fist. Displacements of as little as one thousandth of an inch are accurately measured and amplified many thousand times to give a detailed picture of the strains present. Its sensitiveness is complemented by its ruggedness; the clattering vibrations of a fast-moving train, and the thunderous rolling bumps of a steel-mill fail to impair its accuracy. It has the important additional merit of being readily adjusted after installation by a quick turn of a potentiometer knob. Having no complex, bulky, or unduly delicate accessories, the magnetic strain gage is ideal for the measurement of axial movement, torque, vibration, or almost any mechanical displacement, especially where delicacy of measurement is required of a necessarily rugged instrument that can take it.

Simple in Design

This device is simplicity itself. To a brass frame are rigidly attached two iron cores wound with matched coils. A second frame, to which is attached an armature, is held in a position parallel to the first frame by four leaf springs. These springs allow movement in one direction only. The armature of the second frame is centered between the two laminated-iron-core and coil assemblies. Any motion in the allowable direction causes a change in the air gap of the magnetic path between the elements of the instrument, which in turn changes the reluctance of the magnetic path and hence the impedances of the two coils of the assembly as shown in Fig. 1. Any change of impedance of these coils unbalances the bridge circuit of which they are a part, with a consequent flow of current. This current flowing in the system is proportional to the movement being measured, the calibration of the instrument being linear up to motions of 0.010 inch.

The overall simplicity of construction and operation of this instrument and its attendant ruggedness and stability do not imply any insensitivity. Under most favorable conditions, the magnetic strain gage gives full-scale deflection on an indicating instrument or four inches deflection on a magnetic oscillograph for about 0.0003-inch motion. Even higher sensitivities can be obtained if more sensitive indicating instruments are used with the gage, but measurements of this order are not recommended unless the operating conditions of the measurement, such as temperature change, changes in operating procedure, etc., can be strictly controlled. The gage is used in conjunction with different combinations of attendant instruments that have varied degrees of sensitivities, according to the requirements of the problem being considered.

For measurements of rapidly varying displacements the strain-gage currents are recorded by an oscillograph, using a low-pass filter to cut off frequencies over 300 cycles per second, the approximate accurate ceiling of the gage. For static or low-frequency displacements, having periods of two seconds or longer, either an indicating meter, a graphic meter, or both can be used without a filter. For intermediate frequencies of displacement, periods of less than two seconds to about 0.03 second, an oscillograph is necessary but the filter can be replaced with a damping vane on the oscillograph element. The schematic layout using a Rectox unit, filter, and oscillograph is shown in Fig. 3 while the basic circuit using a wattmeter-type recording instrument with impedance-matching transformer is shown in Fig. 4.

Sensitivity Factors

The sensitivity of the gage is a function of both the power supply and the type of recording or indicating instrument. In turn, the selection of the instrument and the frequency of the power supply depend upon the frequency of the displacement to be measured. Mathematically, the gage sensitivity is directly proportional to the total air gap. The frequency of the power supply also bears on the sensitivity. In the smaller gage the maximum sensitivity is achieved when using a 115-volt power supply at about 800 cycles and having

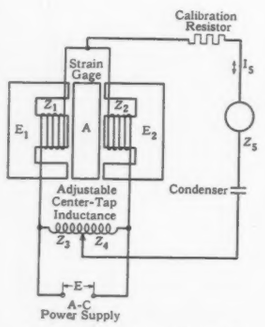


Fig. 1—Basic wiring diagram of the magnetic gage.

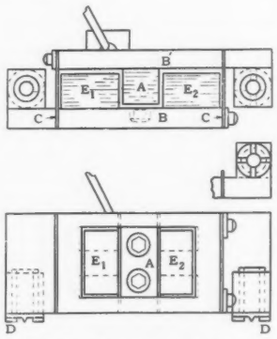


Fig. 2—Gage parts similarly marked for comparison.

Principle of Operation

The principle on which the gage operates is shown in Figs. 1 and 2. E_1 and E_2 are laminated-iron cores which are attached rigidly for Frame B (Fig. 2). A is a laminated iron armature attached to Frame B'. Frames B and B' are connected together by four leaf springs, C, which allow relative motion between the frames in only one direction, and thus act as frictionless guides. When such a motion occurs, the air gap between A and E_1 increases, and that between A and E_2 decreases, or vice versa. This changes the reluctance of the magnetic paths in E_1 and E_2, and consequently changes the impedances of the two coils which are wound on them (Fig. 1). The coils on E_1 and E_2 and the adjustable center-tap inductance are connected in a bridge circuit energized by alternating current. When the coils are thrown out of balance, current passes through the instrument on which readings are being taken.

The sensitivity is determined by the amount of current that passes through the instrument. This current can be increased by "resonating" the bridge with a condenser placed in series with the instrument. Also, maximum power to the instrument can be obtained by a correct choice of the instrument impedance, or else by the use of a matching transformer. An additional advantage of a step-up matching transformer is that it reduces the size of the condenser by the square of the transformer ratio.

The theory of the bridge circuit used was developed by Mr. S. L. Burgwin, of the Westinghouse Research Laboratories. It shows that maximum sensitivity is obtained when Z_3 and Z_4 (See Fig. 1) are as low as possible. This is achieved by using an autotransformer for Z_3 and Z_4 so that the same flux will thread both coils and they will have a large mutual inductance.

a maximum armature motion of 0.010 inch. Depending on the size of gage, nature of test, and other factors, the most effective frequency lies between 500 and 1000 cycles. In general, low-frequency power gives less inductance. On the other hand, frequencies of too great a magnitude introduce excessive core losses and other problems and are not desirable. Under these conditions the gage requires about 15 volt-amperes at a low power factor, and provides full-scale deflection on a standard recording milliammeter for 0.001-inch displacement or on an indicating instrument for 0.0003-inch displacement. Inasmuch as the gage is designed so that the ratio of inductance to resistance is as high as possible, the power factor will be inherently low in the device. In general, the choice of power-supply frequency is determined by the frequency of the displacement to be measured and the degree of sensitivity desired. Where considerations of size and frequency are of no moment, gages for 60-cycle operation can be used with convenience and precision.

When central-station power is available, it is convenient to use 60-cycle excitation because of the ease with which its voltage can be regulated. This lower frequency necessitates a lower voltage in order to keep the gage from overheating. Also an adjustment is required in the condenser capacity if maximum sensitivity is to be obtained.

Ordinarily, gages operated from low-frequency power are larger. Applications with limited space requirements entail the use of the smaller size gage with attendant lessened output and high-frequency power supply. These larger gages are, however, built to give the same sensitivity at 60 cycles as the smaller gages at 800 cycles. Gages of special design for specific uses are made for operation at 115 volts, 60 cycles that will give readings on several indicating and one graphic instrument as well as operating a relay for alarm devices.

Mounting the gage on the test piece is not a critical procedure, which further enhances the ease and simplicity of application and operation. As the mounting of the gage is not a matter of laboratory precision, it is an ideal instrument for field operations. A variation of as much as 1/64 inch can be tolerated between centers of the mounting holes for the gage. Differences in magnetic reluctances are caused by variations in the air gaps through slight mounting inequalities. The resultant unbalanced condition of the coil impedances is readily counterbalanced by means of the potentiometer or variable-center tapped inductance across the two reactors in the bridge circuit.

The two frames containing the coil assemblies and the movable armature respectively are bolted to the machine to be measured by screws through the centers of the two sets of four knife edges (D in Fig. 2). Clamps can be used when tapped holes in the test piece are objectionable.

The gage itself can be carried from one location to another without recalibration. The only prerequisite is that the armature be free to travel through its largest expected motion without striking the stationary laminated cores.

Inherent Advantages

Any type of displacement as a result of mechanical strain can be measured quickly and easily with the magnetic strain gage, providing the vibration frequency does not exceed several hundred cycles a second. A further limitation provides that the acceleration of the gage itself must not be beyond the point where the inertia of the gage will cause distortion of its own mountings.

This gage can be used in a centrifugal field that is strong enough to bend the frame of the gage itself. This is done by reversing the mounting bushings which carry the mounting knife edges. In so doing, the knife edges are removed from the outer edge of the instrument and are located on the axial center-line of the gage. When in that position, any bending of the frame by centrifugal force, while it moves the armature closer to one edge of the fixed core, moves it farther from the opposite edge so that the mean length of gap remains the same and there is no overall change in the reluctance of the magnetic path. Thus, the centrifugal force is neutralized as far as the electrical circuit of the device is concerned.

There is a simple calibrating device that consists of a base and moving platform. The platform is moved by a differential screw arrangement and the amount of motion is indicated on a dial gage graduated in tenths of thousandths

of an inch. This calibration device will accommodate any gage up to eight inches in length.

Types of Application

One of the earliest applications of this device was in its use for the measurement of strains in railroad rails set up by passing trains.[1] Exhaustive tests made possible for the first time by this device demonstrated exactly the nature and extent of eccentric vertical loads on rails, lateral loads on rails, and dynamic stresses in rails. From the data compiled, authoritative general formulas were evolved on these and other stresses encountered in railroad trackage, including web stresses. Subsequent tests were made in another branch of railroad engineering. The strains set up in the locomotive drive rods were measured.

Other industrial applications for which the gage was particularly fitted included measuring strains developed in the frames of the rolls in steel mills. Modern demands on steel rolling mills have been for increased width and thinner gage strip steel. This involves pressures of millions of pounds with the attendant bearing and other allied problems. Early operators, without knowing accurately the pressures involved, operated their screwdowns to bring their rolls tighter together with disastrous results. Another factor is that the flexibility of the mill itself under these pressures may exceed the gage of the strip being rolled. Utilization of the magnetic strain gage as a continuous operating guide gives exact information as to pressures in use, and avoids overloads and resultant breakage or premature fatigue. Also, particularly in rolling thin gages, damage to the rolls themselves is avoided. The product is improved in that pressures at both ends of the rolls can be regulated within plus or minus five per cent, making for uniform gage accuracy. The strain gage also enables the operator to set the pressure of the rolls to conform to the requirements of the metal being handled, various pressures being required for various alloys.

In 1941, exhaustive tests were made on an Oklahoma oil well using the magnetic strain gage for the measurement of strains encountered in the pumping equipment at the surface as well as deep in the ground.[2] This gives an interesting, typical example of the adaptability of the gage to unusual and seemingly impossible situations. Gages were so placed that several different loads and strains were measured as follows: peak polished-rod loads (in oil parlance, the polished rod is the one that passes through the packing in the stuffing box at the top of the well), effective pump-plunger forces (measured

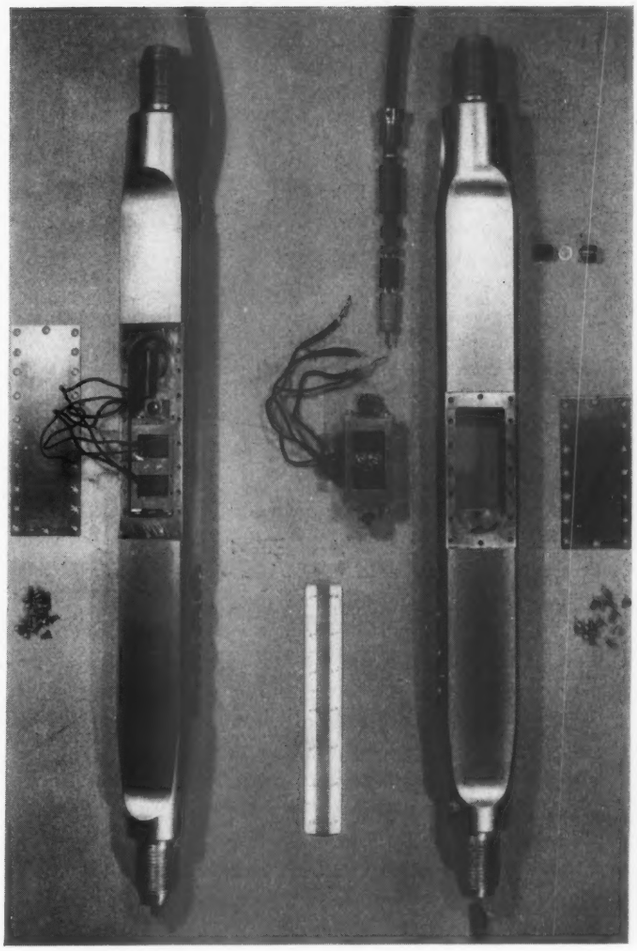


Fig. 5—Exploded view of submersible gage and casing.

at the bottom of a 3500-foot well), peak torques on the crankshaft and the effect of the prime mover on these forces and loads. A photograph of the component parts of the strain-gage assembly used in the oil-well tests is shown in Fig. 5.

Because of the high pressures at the bottom of the well, a differential of pressures was created between the inside and outside of this special gage casing. The interior of the casing was filled with oil and the casing itself fitted with a copper bellows with sufficient amplitude of movement to equalize the divergent pressures.

An idea of the diversity and cogency of the data assembled in a test of this type is exemplified by the oscillograph of one of the tests as shown in Fig. 6. The precise timing of the

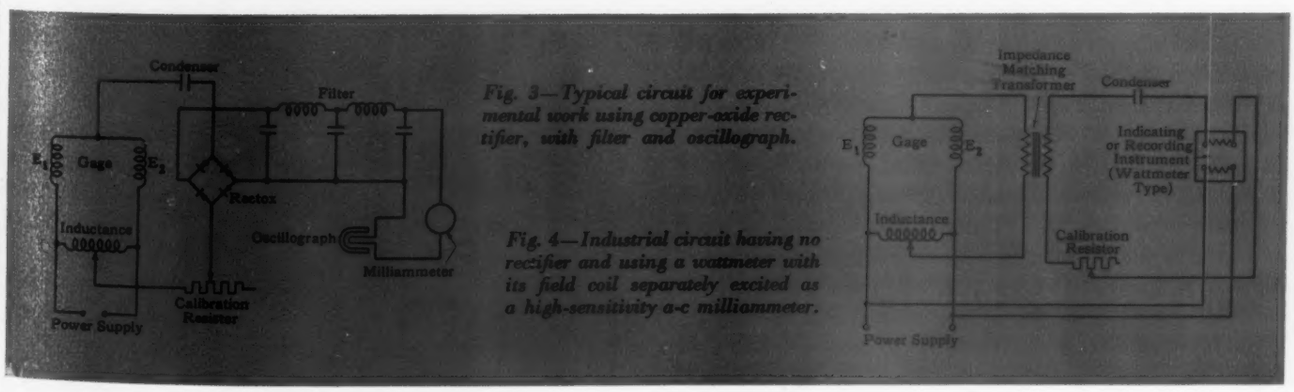


Fig. 3—Typical circuit for experimental work using copper-oxide rectifier, with filter and oscillograph.

Fig. 4—Industrial circuit having no rectifier and using a wattmeter with its field coil separately excited as a high-sensitivity a-c milliammeter.

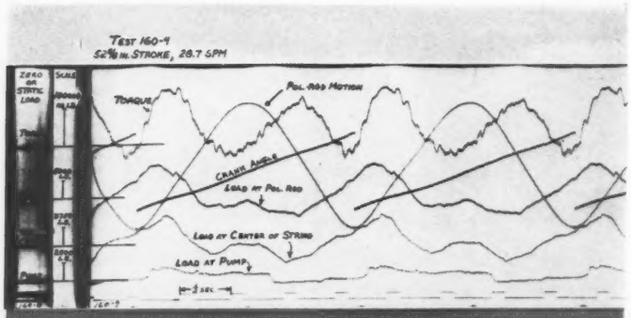


Fig. 6—Correlation of many forces with several strain gages.

forces and loads permits a nicety of analysis not heretofore possible where components of the system presented such problems of accessibility.

Tests were recently inaugurated which seemingly had awaited the development and refinement of just such a gage. In cooperation with the U. S. Coast Guard a number of magnetic strain gages were installed in a Coast Guard harbor cutter.[3] These magnetic strain gages were installed on a special propeller shaft in the cutter for indicating strains of propeller torque and thrust while the ship was maneuvering. This was probably the first time that such data was recorded simultaneously on a single oscillogram.

This installation also presented problems peculiar to this type of test. To eliminate error by any bending of the shaft, gages for measuring both torque and thrust strains were installed on opposite ends of shaft diameters as shown in Fig. 7. The mean of the readings of the two gages cancelled any displacement caused by bending of the shaft. The gages were also mounted with knife-edged bushings in the reversed position so that the centrifugal effects would be canceled.

Valuable data was accumulated, especially with regard to torsional vibrations at critical speeds, distribution of currents in the propulsion equipment during the various maneuvering stages noted with the accompanying torque and thrust.

Two new uses for the magnetic strain gage are pertinent examples of its diagnostic and preventative use in connection with industrial equipment ailments. The strain gage is being used to determine the starting torque and thrust of waterwheels after varying shutdown times. After a stoppage of any length of time the bearing oil is believed to be squeezed to molecular thickness and this film is sometimes broken when operation is resumed. In this application, as in the ship-propeller investigation, torque and thrust are each measured by two gages on opposite sides of the shaft to cancel any bending effect. However, in the ship-propeller tests, readings were taken on a run with continual revolutions of the shaft, necessitating the use of collector rings and brushes to maintain electrical contact with the gages. The critical period of bearing operation is during the first half revolution of the shaft, during which time difficulties may arise because of inequalities in the bearing surfaces cutting through the pressure-thinned oil film. The scraping effect of metal on metal is cumulative and because less than a complete revolution of the shaft is necessary for the test, long leads suffice for the electrical connections, and collector rings are obviated.

The other application, preventative in nature, rather than diagnostic, was in connection with the drive-shaft system of the huge wind tunnel at Wright Field, near Dayton, Ohio.[4] A 40 000-hp motor drives a pair of 40-foot fans on a solid steel shaft 120 feet long and it was desired to know if any torsional vibrations might develop. Several factors enter into the possibility of this occurrence. The acceleration of the system, with its great inertia, to full speed at 300 rpm is accomplished slowly, over a period of an hour. Passing slowly through a resonant period might give torsional vibrations a chance to build up. Further, the nature of the wind tunnel demands that various gradations of speed be available for various tests and torsional vibrations must not show up in any usable speed range. To this end, magnetic strain gages were utilized to check for torsional vibrations of any moment throughout the complete range of the system. The negative findings of the gage were as informative and valuable as the negative findings of an electrocardiogram; both are the go-ahead sign for normal activities with perfect safety.

The magnetic strain gage is not adequate for measuring highly accelerated motions of high amplitude and frequency, such as impacts and explosions, but the fields of application for the device are constantly expanding. Wherever the problem is one of strain displacement, at a frequency of not over several hundred cycles a second and within the inertia limitations of the armature mass, this gage will perform exceptionally well. Despite handicaps of accessibility, inundation in liquids, subjection to centrifugal force, subjection to rough usage or other factors usually considered fatal to the accuracy of other precision measuring devices, the magnetic strain gage functions with laboratory precision but it entails no laboratory precision for installation or operation.

REFERENCES

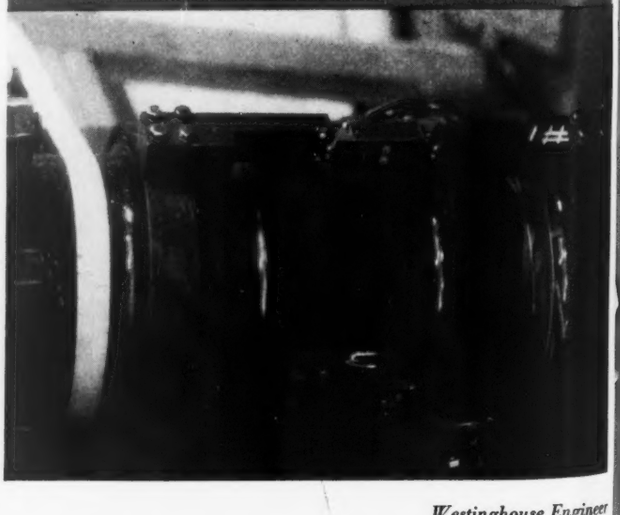
1—"Stresses in Railroad Track," S. Timoshenko and B. F. Langer, *Applied Mech. Sect. ASME Transactions*, December 15, 1932.

2—"Oil Well Tests Suggest New Rating Standards," H. E. Dralle and E. H. Lamberger, *Drilling and Production Practice*, 1941.

3—"Test of Transient Conditions in Maneuvering a Coast Guard Harbor Cutter," Lieutenant Commander H. H. Curry, USCG, and J. C. Fink, Westinghouse Elec. & Mfg. Co., Society of Naval Architects and Marine Engineers, November 13 and 14, 1941.

4—"Power for Man-Made Hurricanes," L. A. Kilgore and J. C. Fink, *Westinghouse ENGINEER*, November 1941, Pages 71-73.

Fig. 7—Gage mounting for thrust and torque measurements.



Comparison of Lightning-Protection Methods

Like the challenger to a duel, lightning offers the transmission engineer only one choice, that of weapons. And this is no easy choice. The engineer may elect to use spill gaps, being attracted by their simplicity and low cost. But these are not as effective in protecting the system as lightning arresters or protector tubes. To increase the reliability of gaps he may supplement them with fuses or circuit breakers. Doing this destroys the initial advantage of gaps and calls in two other factors: maintenance, and possible jeopardy of service and production.

LIGHTNING protection on electrical systems has two principal objects. One is to prevent damage to apparatus, the other to preserve uninterrupted service by the means most economical in equipment and maintenance. Spill gaps[1, 2, 3, 4] and the standard protective devices such as arresters and De-ion protectors have been used for these purposes. Some differences of opinion exist on the relative merits of the two methods of protection. Experience over a number of years has been accumulated with both. This experience and the significant data on lightning surges on systems collected during recent active field investigations make possible an analysis of the two methods and a comparison of their effectiveness in accomplishing the two purposes of protection.

A considerably greater fund of experience exists with arresters and the De-ion gaps than with spill gaps, since spill gaps have been used on only a comparatively few systems. Moreover their use has been declining. There are several reasons for this. On high-voltage systems relatively short gap settings are necessary to protect the apparatus. This results in numerous operations from lightning and other surges that produce outages unless additional functional equipment is used, such as fuses or breakers. Fuses must be replaced after each operation. To reduce this maintenance, repeater fuses have been used. Fuses with as many as eight shots have been recommended. To protect substation equipment two and three sets of gaps have sometimes been installed in parallel. The material and space requirements of such fused gaps approach those of arresters, and require appreciable service and maintenance.

E. BECK
Lightning Arrester Engineer
G. D. McCANN
Central Station Engineer
Westinghouse Electric & Mfg. Co.

Basic impulse levels for distribution apparatus are higher in relation to their operating voltages than for high-voltage equipment. Therefore, the gaps used on distribution circuits have relatively higher breakdown values, but in actual inches they are short. Fusing the gaps is impractical. When the gaps flash over the circuits must be cleared by feeder or station fuses or breakers. In the early days of gaps many service interruptions occurred as the result of short circuits produced by birds and other foreign objects. Attempts to eliminate this trouble led first to double gaps, and then to complete enclosure of one of them.[3, 4] Such gaps have limited surge-current capacity and fault-current clearing ability. Thus, to enable gaps to give the desired protection they are being supplied with various adjuncts, thereby nullifying the single advantage of the gap, that of simplicity and low cost.

Ground-fault impedance is important in the application of spill gaps, for the fault current must be sufficient to open fuses or breakers if prolonged arcing of the gap and consequent service outage and damage are to be avoided. Under some conditions with the gaps grounded to secondary neutrals with high ground resistance prolonged arcing has damaged household appliances. Arresters or De-ion gaps clear themselves, and are therefore, free from these difficulties.

Relative Protection for Power Systems

The characteristics pertaining to protection on power systems are shown by the curves in Fig. 1. There has been considerable difference of opinion among advocates of spill gaps as to the proper gap spacings. As a result spacings have varied over wide ranges as illustrated by the low points in Figs. 1 and 3. Curve *B*, for suggested spill gaps in Fig. 1, would, however, probably provide a reasonable margin for the protection of the more modern transformers, and hold the number of gap operations in check as far as possible. The arrester impedance drop is plotted in Fig. 1(a) at 20 000 amperes per pole, a standard test figure, and one apparently rarely experienced by arresters in stations. The highest published record of station-arrester discharge current is 15 000 amperes. The modern arrester gives a good protection at considerably higher currents. The curves show that the surge-voltages are limited more by arresters than by spill gaps, and experience supports this. The statement has been made[5] in connection with the Wallenpaupack-Siegfried line that "Spillway protective gaps set at 42½ inches were installed on each phase conductor—but spillway gap flashovers were frequent at Wallenpaupack until 1934 when 220-kv arresters were in successful operation. Since then three spillway gap flashovers

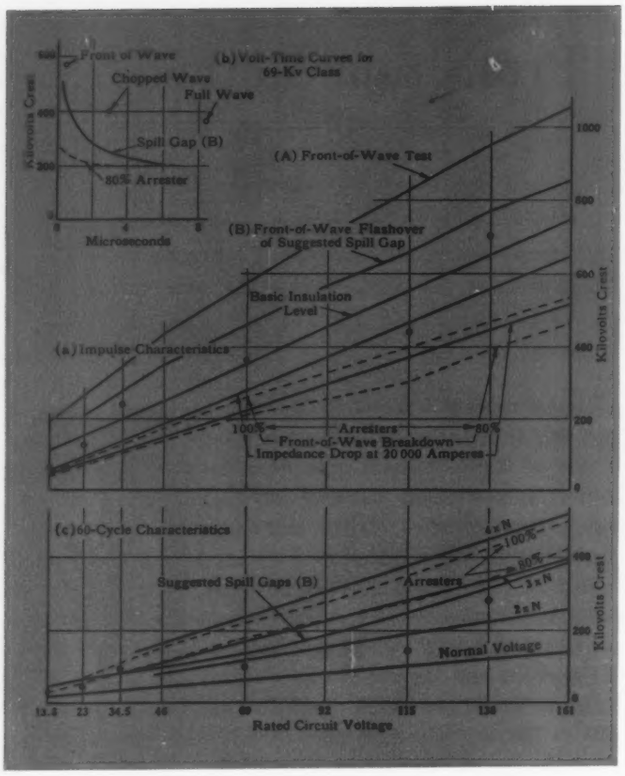


Fig. 1—*Characteristics of protective devices and transformers on power systems. In (a) and (c) the circles show the characteristics of the shortest spill gaps reported in the literature. In (b) the circles are the demonstrated impulse strength of the transformer for three kinds of waves.*

have occurred, but none were on the two protected phases."

Sixty-cycle characteristics are shown in Fig. 1(c). Gap spacings short enough for good protection produce a serious number of service interruptions unless additional equipment is used to interrupt the fault current and restore service, as is evident from data available on arrester discharges, switching surges, and the reported experience with gaps. Field investigations show as many as eight discharges per year in a three-phase arrester bank. The average[6] is about 0.7. These figures represent the number of operations and outages to be expected from unfused rod gaps with sixty-cycle breakdown of the same order as the arresters, about three times normal line-to-neutral voltage. This corresponds approximately to the suggested gap, Fig. 1 (Curve *B*). Gaps appear to be in use with sixty-cycle breakdowns as low as 1.35 times normal. These naturally experience more lightning and switching-surge discharges.

A summary of available data[7] on the relative magnitudes of switching surges is provided in Fig. 2. The curves indicate that from 3 to 20 per cent of all switching surges are as much as three times normal, while from 50 to 90 per cent exceed one and one-half times normal. Thus, the number of discharges on the short gaps can be increased several fold from both switching and lightning surges. One user of short gaps reports[2] a general average of 3.4 discharges per single-phase gap per year, and 6.5 discharges for gaps in stations at ends of lines. From data obtained during recent lightning investigations a factor for translating single-phase figures to three phase has been determined as 1.7. This gives 6 and 11, respectively, as the number of surges discharges per three-phase spill gap.

The proportion of total system outages represented by these figures is important in evaluating the effect on service. Usually more outages occur on lines than at stations. Experience available on many lines involving 13 765 mile years of service on 6916 miles of line without ground wires, covering voltage classes from 6.9 to 220 kv, shows that in any one year the number of outages on a given line may vary from 0 to 2.3 per mile per year, the general average being 0.4. The data shows little influence of circuit voltage. Five to ten outages per year because of gap flashover would be a most serious increase for substations connected to lines of normal length. This has been borne out by operating experience, which has shown it necessary to fuse the gaps to achieve reasonable service continuity.

Relative Protection on Distribution Systems

Standards for front-of-wave impulse tests of distribution transformers have not yet been established. Curve *A*, of Fig. 3, gives an arbitrary set of figures, probably reasonably accurate. It is based on the standard tests for power transformers, one voltage class lower.

Comparing the sixty-cycle crest breakdown of gaps and arresters, it appears that spill gaps in use at present are of about the same breakdown levels as arresters. Therefore, the number of arrester discharges that have been recorded in lightning studies should be an index to the number of gap operations to be expected. The field data[6, 8] indicates a general average of 0.6 discharge per distribution transformer per year. On urban circuits, the figure is 0.4 discharge per year, while on rural circuits it is 1.0 per year. This is a significant figure. Inasmuch as there are about three million distribution transformers installed in this country, it represents a lot of operations in a year. It means that on a rural circuit

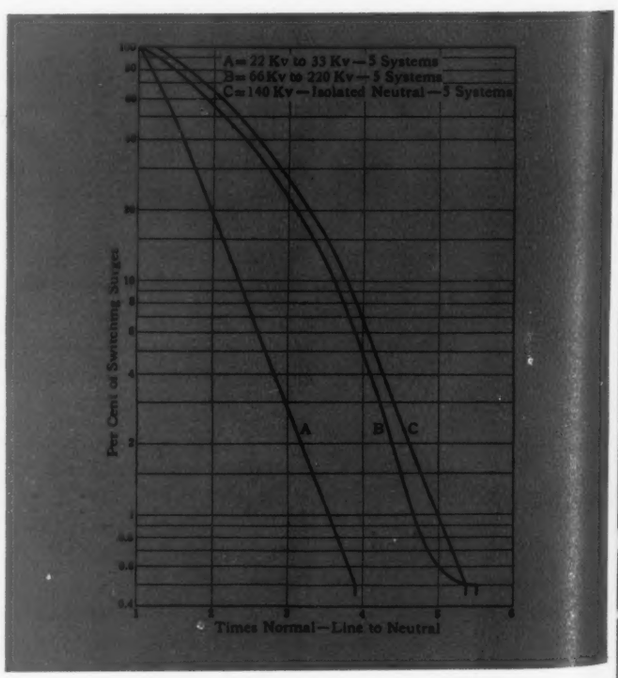

A = 22 Kv to 33 Kv—5 Systems
B = 66 Kv to 220 Kv—5 Systems
C = 140 Kv—Isolated Neutral—5 Systems
Per Cent of Switching Surges
A
B
C
Times Normal—Line to Neutral

Fig. 2—*Probability of voltages of switching surges.*

with 100 spill-gap protected transformers, there will be 100 trip-outs per year, which calls for the replacement of 100 fuses or 100 breaker operations. This is largely responsible for the decreasing use of simple spill gaps for protection against outages caused by lightning and other surges, and the increasing reliance being placed on protective devices such as lightning arresters and De-ion gaps.

Relative Amounts of Material Involved

In normal times the amount of material used either in a gap or an arrester is not of appreciable moment because it is relatively insignificant in each. However, with present shortage of materials even small differences in materials should be considered. The apparatus used in the production and distribution of electrical energy represents an investment of some 14 billion dollars. About 70 million—only one-half of one per cent—represents arresters, De-ion protectors, and other lightning protective devices. These protect not only the utility equipment, but also the industrial equipment served and the flow of its products, which comprises about 75 per cent of our industrial production. A lightning outage may not damage much apparatus, but may have serious consequences in the loss of time and material in process, compared to which the cost and material in the arresters are trivial. The material involved in any form of protective device is a small consideration. With an average expectancy, as already pointed out, of from 0.7 to 2 lightning surges per substation and 0.6 per residential transformer per year, it would not take long to waste in industrial time and material the equivalent of the material involved in protective devices. The simple spill gap obviously requires in itself less material than any of the conventional protective devices. However, because it provides a lesser degree of overall protection, this saving in material is far more than offset either by damage to associated apparatus or loss of material in production by disruption of service. When the gaps are provided with fuses and other auxiliaries to give them a more comparable protective ability this difference disappears. In fact such a procedure, when carried to its logical conclusion results in the development of a protective device as efficient as possible both in its protective qualities and materials used. This has been the history of the development of the lightning arrester and the De-ion protector.

Conclusions

Viewed either from the standpoint of protection or materials involved spill gaps are not good substitutes for lightning arresters or protector tubes. The spill gap does not provide as reliable protection over the range of wave shapes encountered, Fig. 1(b), because of its steeply rising impulse-breakdown characteristic and because of its variable nature. The arrester breakdown time-lag characteristic is flat over a wider range, and is not influenced so much by rate of rise of surge voltage. Because arrester gaps are enclosed and the best types are equipped with pre-ionizing means, their breakdown is consistent and uniform regardless of ambient conditions. Unless additional apparatus is used to interrupt the fault produced and to restore service quickly, the spill gap spacings necessary to obtain a satisfactory degree of protection against apparatus damage result in numerous gap operations and consequent circuit outage. These functions of protection and circuit clearing are inherent in the arrester and De-ion gaps. In brief, where the spill gap promotes outages, the arrester or De-ion protector prevents them. For a system to operate with spill gaps as reliably as it would with standard lightning protection, additional servicing, maintenance equipment, and material are required. It is seldom, if ever, desirable to economize on insurance. The present demands on electrical power supply are enormous. More than ever before the industry must keep its record of reliability intact.

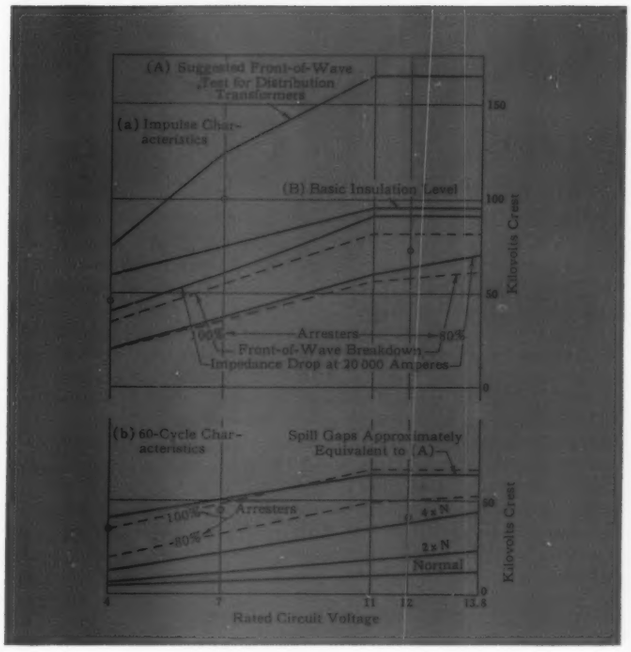


Fig. 3—***Characteristics of protective devices for distribution systems. Industry values for the demonstrated front-of-wave impulse strengths of distribution transformers are not available. Those plotted in curve (A) for Fig. (a) are based on those for power transformers of the next lower voltage class. The front-of-wave flashover voltages of De-ion type protectors lie between curves (A) and (B). The circles on the charts denote the flashover characteristics of the shortest spill gaps reported.***

REFERENCES

1. "Application of Spill Gaps and Selection of Insulation Levels," H. L. Melvin and R. E. Pierce, *Electrical Engineering*, Vol. 56, 1937, p. 689.
2. "Repeater Fuse Spill Gaps Reduce Lightning Outages," M. H. Lovelady, *Electrical World*, Vol. 109, 1938, p. 1045.
3. "Low Cost Bird-Proof Gaps," C. E. Bathe, *Electrical World*, Vol. 117, 1940, p. 1003.
4. "Bird-Proof Gaps Cut Rural Line Outages," J. A. Tyvand, *Electrical World*, Vol. 116, 1941, p. 71.
5. "Lightning Investigation on Wallenpaupack—Siegfried 220 KV Line of Pennsylvania Power and Light Company," Edgar Bell and T. W. Packer, *A.I.E.E. Transactions*, Vol. 61, 1942, p. 196.
6. "Electrical Transmission and Distribution Reference Book," a book, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania, Chapter 12.
7. "Insulation Coordination," Philip Sporn and I. W. Gross, *Electrical Engineering*, Vol. 56, June, 1937, p. 715.
8. "Discharge Currents in Distribution Arresters—II," K. B. McEachron and W. A. McMorris, *A.I.E.E. Transactions*, Vol. 57, 1938, p. 307.
9. "Application of Station Lightning Arresters," A. C. Monteith and W. G. Roman, *Electric Journal*, Vol. 35, March, 1938.

What's New!

Better Searchlights—Without Critical Materials

ENGINEERS are daily performing miracles to meet the desperate shortages of critical materials. One has to do with Westinghouse searchlights such as are now being used in large numbers to protect factories, railroad bridges, river locks, dams, and other war-important structures against the saboteur.

The housings of these searchlights have traditionally been made of cast aluminum, the reflector of Alzak aluminum. Although cast iron and rolled steel have been substituted for the aluminum housing, the searchlight weighs one and one-half pounds less—not more, a silvered glass reflector replaces the aluminum one and gives a slight overall-life improvement in optical efficiency, and the total cost has been reduced (the eighteen-inch searchlight can now be had for the price of the former sixteen-inch unit).

Critical materials are entirely avoided. Although chrome-plated steel has been substituted for the aluminum of the secondary reflector, even the copper that normally is used as a base coat for the chromium is saved by a process by which chromium can be plated directly to steel.

D. E. Henry, electronics engineer, metering ultraviolet rays.

Electronic Meter Measures Ultraviolet

TIMES have changed. Mark Twain once said that everybody talks about the weather, but nobody does anything about it. Now something is being done about it. Weather cannot be controlled, but with new devices many components that go to make up what is generally known as "weather" are analyzed and their effect on animal and plant life weighed. Stations have been long established for the measurements of rainfall, terrestrial magnetism, cosmic-ray bombardment, astronomical phenomena, atmospheric pressures, wind pressures, and many other allied manifestations. However, accurate quantitative determination of the ultraviolet emanations from the sun awaited the development of a new electronic metering device.

A photoelectric cell sensitive to ultraviolet rays has been perfected in the Westinghouse Lamp Research Laboratories under Dr. H. C. Rentschler. It is based on the fact that the zirconium photoelectric cell responds only to radiations shorter than 3150Å or the erytrema producing wave band. Ultraviolet radiations impinging upon the zirconium cathode cause a current to flow proportional to the effective intensity of the radiation. The current charges a condenser to a preset capacity whereupon it discharges, actuating a relay that operates a counter. The closing relay makes an audible click, which is taken as a unit of ultraviolet energy.

Having an instrument capable of scientific accuracy in ultraviolet ray intensity determination, it is now possible to establish stations throughout the country and correlate this data with public health and crop statistics and other data, showing their relationship. Thus a new instrument takes its place in the sun to serve humanity.

Ultraviolet Safeguards Bottling

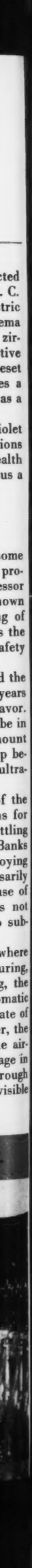
IN 1801 a comparatively obscure German scientist noted that some form of energy beyond the violet end of the visible spectrum produced a definite effect on silver chloride. It is a far cry from Professor J. W. Ritter's meager notes on a newly discovered force, now known as ultraviolet rays, to the twentieth century high-speed bottling of soft drinks. Yet it is the adaptation of this discovery that enables the bottling of 1260 bottles of Pepsi Cola per hour with sanitary safety and uniformity of finished products.

The time between the photographic discovery of these rays and the production of the Westinghouse Sterilamp was bridged by 141 years of patient research and development in many avenues of endeavor. This culminating device is a long ultraviolet-transmitting glass tube in which is an inert gas, electrodes sealed in each end and a small amount of mercury. Attached to the 115-volt, 60-cycle line the Sterilamp becomes an efficient cold-cathode, mercury-vapor type generator of ultraviolet rays.

Producing usable bactericidal rays at a rate 200 times that of the midday sun, this lamp has found a great number of applications for preservation of foods and maintenance of public health. The bottling industry has found the use of Sterilamps especially valuable. Banks of these lamps are used in their huge syrup storage vats, destroying both bacteria that are harmful to humans, and bacteria, not necessarily harmful to humans, but affecting the product adversely. This use of invisible rays to exterminate bacteria in the syrup alone does not insure uncontaminated beverages because the bottles were also subjected to air-borne bacteria.

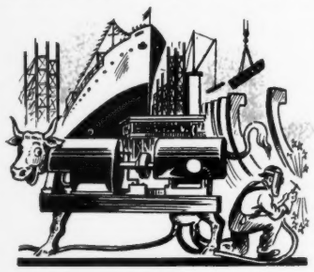
After emerging from the automatic bottle-washing machines where they are subjected to high-pressure jets of filtered water for scouring, then to sterilization in an alkali solution and thorough rinsing, the bottles are individually inspected. They then pass to an automatic conveyor that moves them through the bottling machines at a rate of 137 to 210 a minute. Before the actual bottling process, however, the bottles are subjected to irradiation by Sterilamps, destroying the air-borne bacteria. The finished product is therefore a sterile beverage in a sterile container, and there can be no deterioration of quality through bacterial growth. A case of an unseen enemy destroyed by invisible rays. The effectiveness is seen only in the result.

Bottles passing under Sterilamp hoods before being filled.



PERSONALITY PROFILES

One day, several years ago, *C. A. Rober*, in charge of a welding shop, was forced to adopt a welding practice of the design engineers, who insisted the theory was correct, but which Rober's practical experience told him was wrong. Next day several of the welds failed with rifle-shot reports. When one of the welding engineers asked, "What was that?" Rober calmly replied, "That is your welding theory exploding." Henceforth the job was done by Rober's method. Today he is Welding Supervisor of the Fore River Plant of the Bethlehem Shipbuilding Division of Bethlehem Steel Company. At his direction are 3000 production welders, 1000 tack welders, and 750 learners. Since leaving Lowell Institute he has had 20 years' experience in all the practical phases of welding—which, although he is still only 42, makes him an old-timer in the welding industry.



Mr. W. B. Strathdee also has had long experience with welding. Since 1929 he has been assisting in the solution of welding problems of companies in New England. A graduate of Tufts in 1927, Strathdee headed for the then young welding industry as soon as he completed the student course at Westinghouse. Since 1929 he has been located in the Boston office of Westinghouse as a specialist in welding.

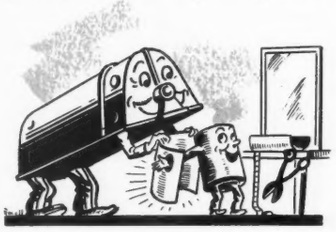
* * *

T. R. Lawson spent his childhood in Crisfield, Maryland, duck-hunters' paradise. It is only natural that hunting should be his lifelong guide. He hunted up a degree of Bachelor of Science in Electrical Engineering at Johns Hopkins University ('28) and then hunted up a job with Westinghouse, starting the same year in the Student Course. In the Motor Generator and Welding Section, hunting down troubles led him, in 1937, to work as an a-c motor and control specialist. Bringing down big ones with little shot, it was natural that he would get into the business of firing electrons at the right moment to bring down heavy currents; since 1941 he has been in the Electronic Control Section.

Several years ago, when the Resistance Welder Manufacturers Association was a very young organization, *E. J. Del Vecchio* was asked to be chairman of its publicity committee. Each year since, he has tried to resign to let someone else have the post, but without success. Which often happens when someone does his work well. As if this important function in the association were not enough, Del Vecchio is also a member of the educational and the program committees. Of course all this can be but a part-time job. The wherewithal to pay rent and taxes, he obtains from his position as Assistant Sales Manager of the Taylor-Winfield Corporation, having first been in charge of its experimental division. A fund of practical experience in the use of resistance welding came to him while serving as electrical engineer for the Firestone Steel Products Company, of Akron.

* * *

One of *J. Raymond Erbe's* associates appraised him thusly: "You can hardly mention anything he can't do. He can fly a plane, survey land, run a precision lathe or planer, play a piano, and does them well, too." Erbe's varied skills probably result because he took seriously a bit of advice given him by an engineer friend when he left high school: "Son, along with your formal engineering education,



get yourself lots of practical experience." Before college he was with the General Electric Company as a tool and die maker, then at Westinghouse as a machinist. He interrupted his engineering studies at the University of Alabama to get three years' experience in a steel mill as an electrician. After graduation in 1934, he variously worked for several months with Speer Carbon Company on carbon brushes, then for the American Steel & Wire Company, and later for Carnegie-Illinois Steel Company. He moved over to Westinghouse in 1937 as a tester of large generators and motors. In 1940 he believed he had accumulated sufficient practical experience to become a steel-mill application engineer. Much of his effort since has been concentrated on steel-mill auxiliaries, such as screw down, hot saws, wire lines—and now with a whole new phase of the steel industry—electrolytic tinning.

* * *

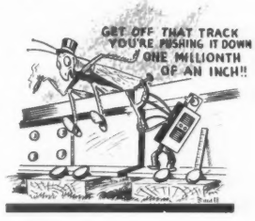
G. D. McCann comes from the West, where broncobusting is common. But McCann has undertaken to tame a "bronco" far wilder than ever tossed a cowboy out of a corral. This is lightning. In only four years with Westinghouse he has become an internationally known authority on the subject. First,

lightning had to be caught, so McCann and his associates created several special devices for the purpose. Among these are the fulchronograph, automatic cathode-ray oscillograph, and photographic surge recorder. Armed with these McCann has climbed fire towers, skyscrapers, transmission-towers, and radio masts to collect a mass of valuable information on lightning and its behavior. McCann was granted a Ph.D. by California Institute of Technology in 1939, his bachelor's and master's degrees in electrical engineering having been obtained from the same school in 1934 and 1935 respectively.

E. Beck, the other member of the team discussing the relative merits of spill gaps and arresters for lightning protection, has written for these pages before (February, 1942).

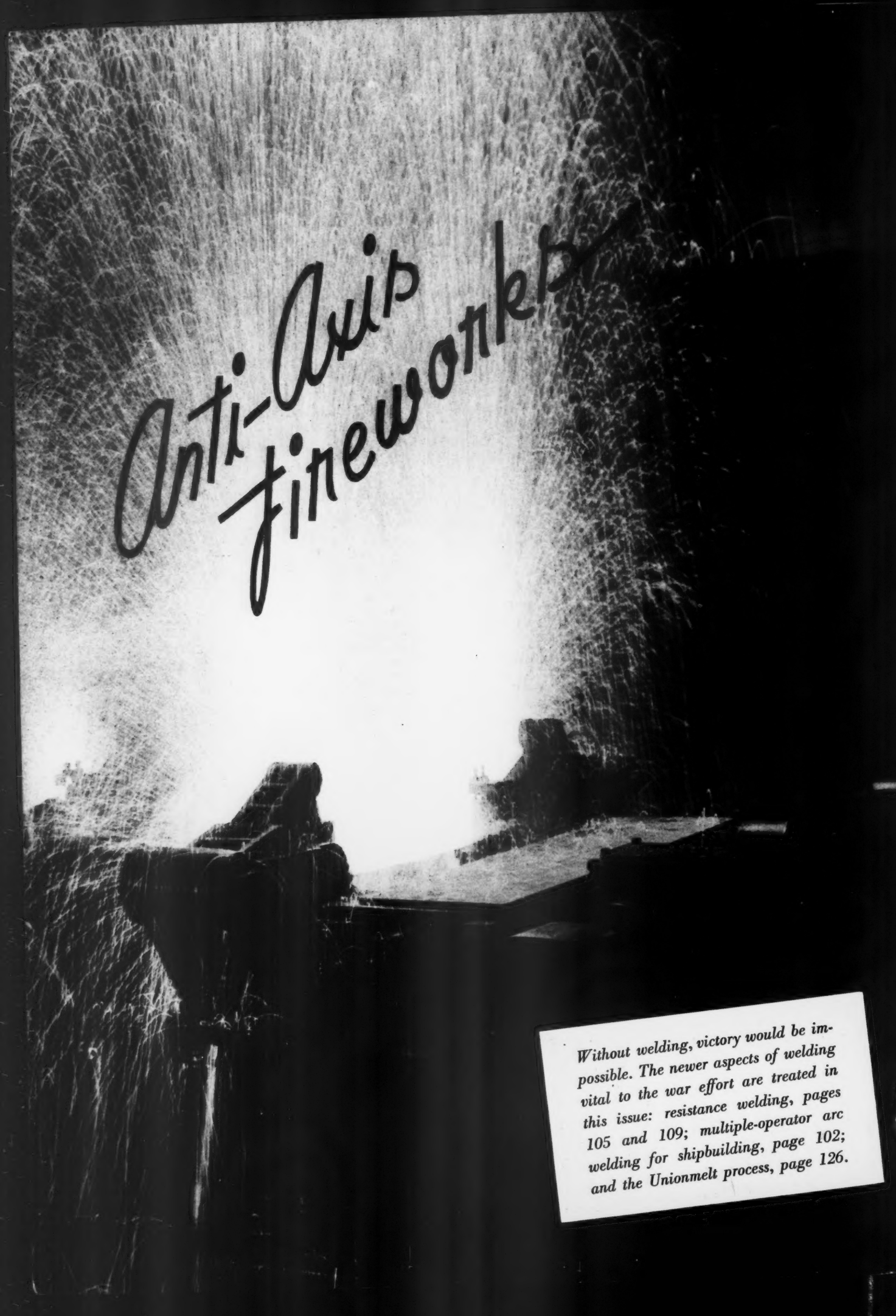
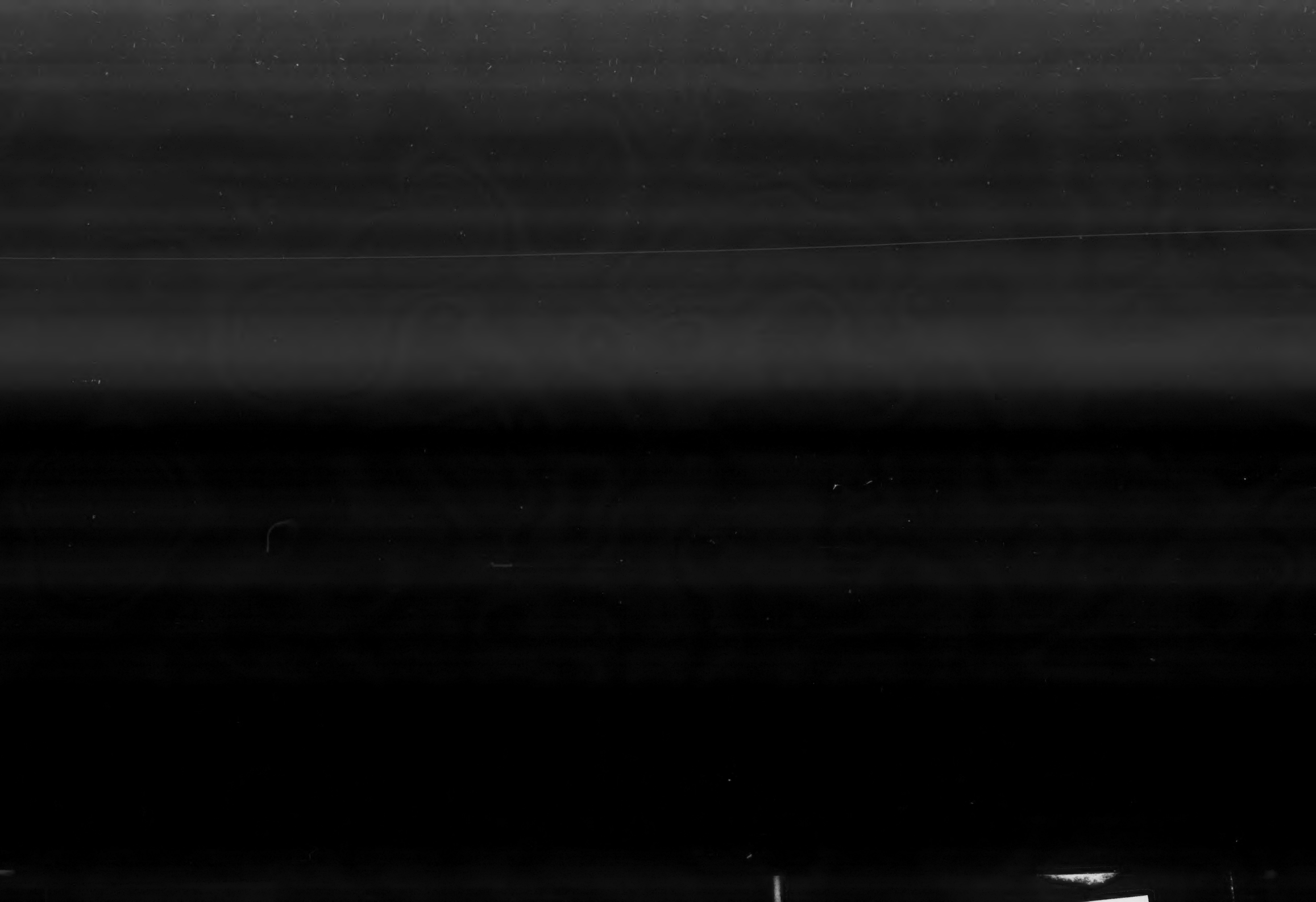
* * *

Travel broadens one if capital is made of observations en tour. *Mr. B. F. Langer* evidently made the most of his extensive travels from coast to coast. His analysis of locomotive sway and "wabble" led to design improvements which paved the way for safe operation of locomotives at high speed. His work in this line achieved international recognition, and in 1939 he was employed in an advisory capacity by the French National Railways, leaving France just before Hitler's entrance. Born in New York, he completed his education on the West Coast, attending Stanford University where he received his B.A. degree in 1926 and Bachelor of Science in Mechanical Engineering in 1928. Coming with Westinghouse shortly after, his work has been mainly in the Westinghouse Research Laboratories.



* * *

Mr. S. F. Henderson was graduated from the Armour Institute of Technology with a degree of B.S. in E.E. in 1926, coming with Westinghouse the same year. His work has largely been designing and developing motors, mainly for use in hazardous locations. Author of papers on steel-mill motor applications, he has worked closely with the NEMA and Underwriters Laboratories in setting standards for motor design for use in mines, oil fields, tunnels, and other danger zones.



Without welding, victory would be impossible. The newer aspects of welding vital to the war effort are treated in this issue: resistance welding, pages 105 and 109; multiple-operator arc welding for shipbuilding, page 102; and the Unionmelt process, page 126.